Initial Radiometric Performance and Data Quality of the OLI and TIRS Landsat-8 sensors

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LDCM
LANDSAT-8

data continuity mission

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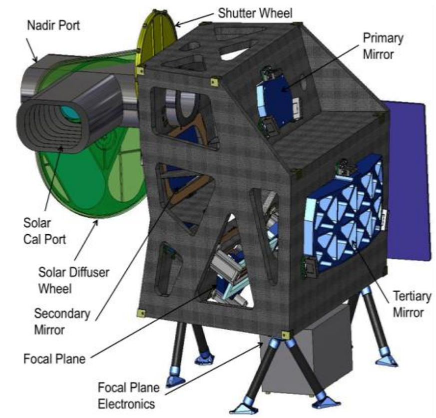
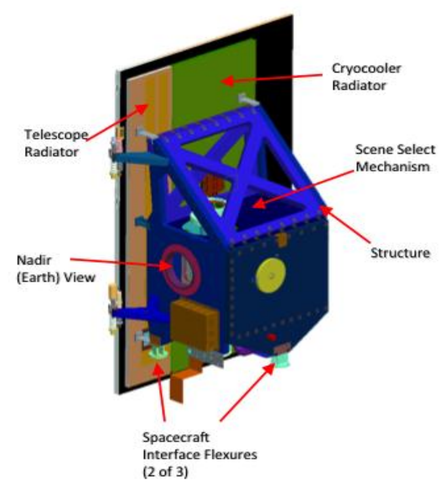
Outline

- OLI Radiometric Performance
  - Noise
  - Stability
  - Uniformity
  - Absolute Calibration
  - Artifacts
- TIRS Radiometric Performance
  - Noise
  - Stability
  - Uniformity
  - Absolute Calibration
  - Artifacts
- Upcoming reprocessing effort
- L-8/L-7 Comparative Images

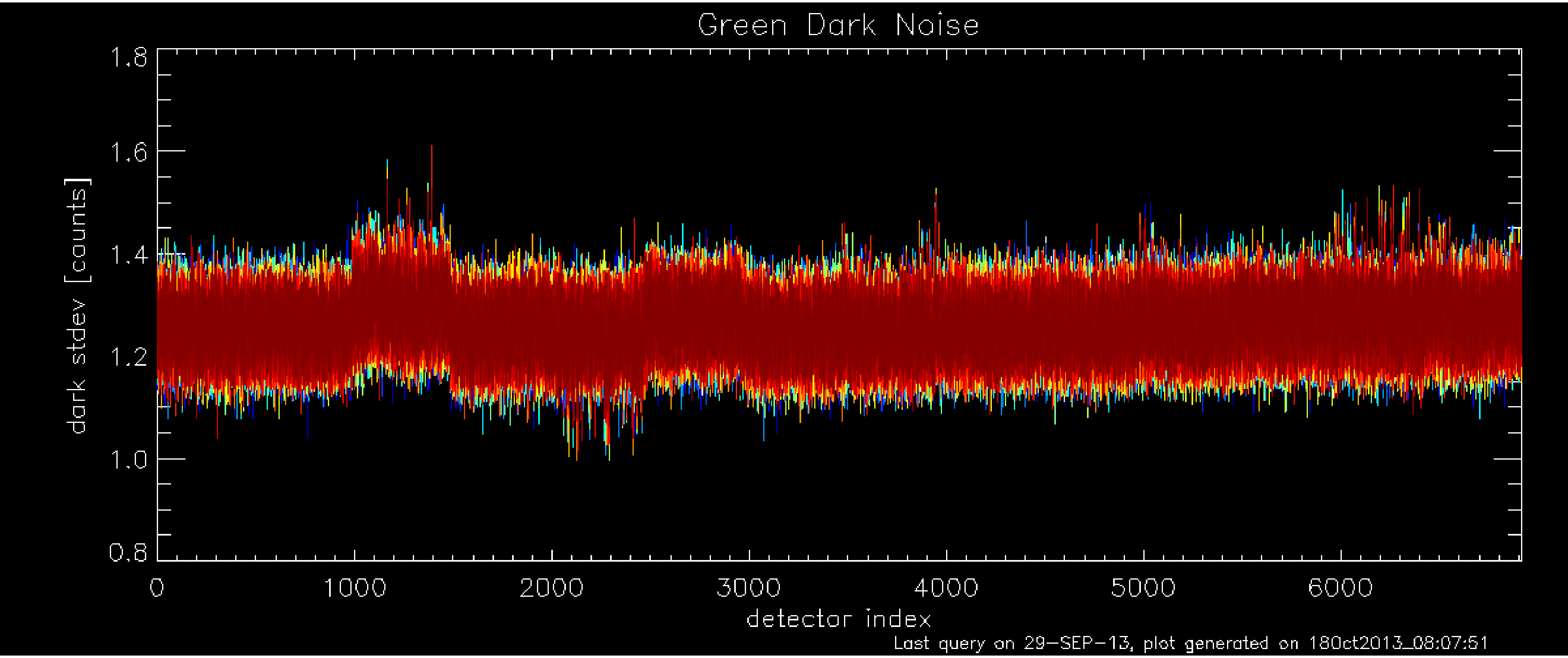




OLI

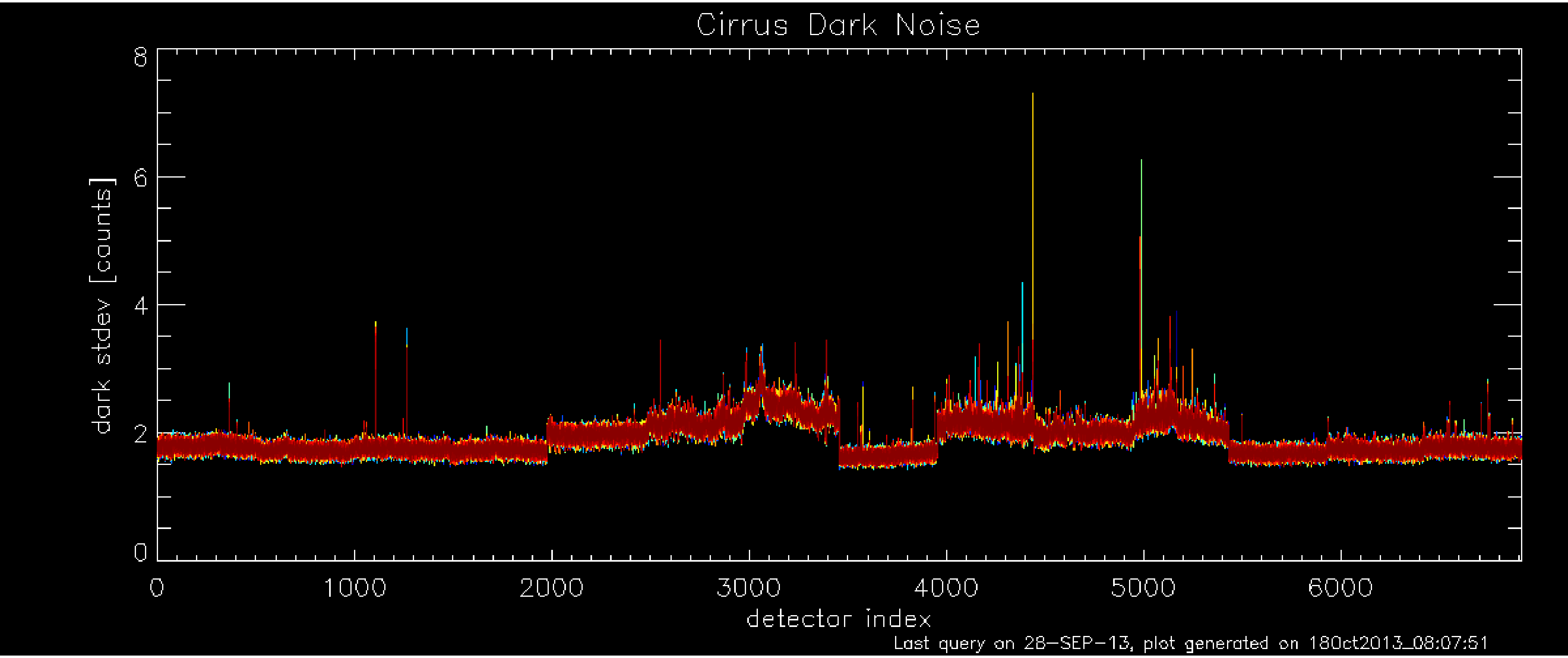
- Noise
  - Dark
  - SNR
- Stability
  - Dark
  - Responsivity
- Uniformity/Relative Calibration
- Absolute Calibration
- Artifacts
- Summary

OLI Dark Noise - Green



14-bit DN's

OLI Dark Noise - Cirrus



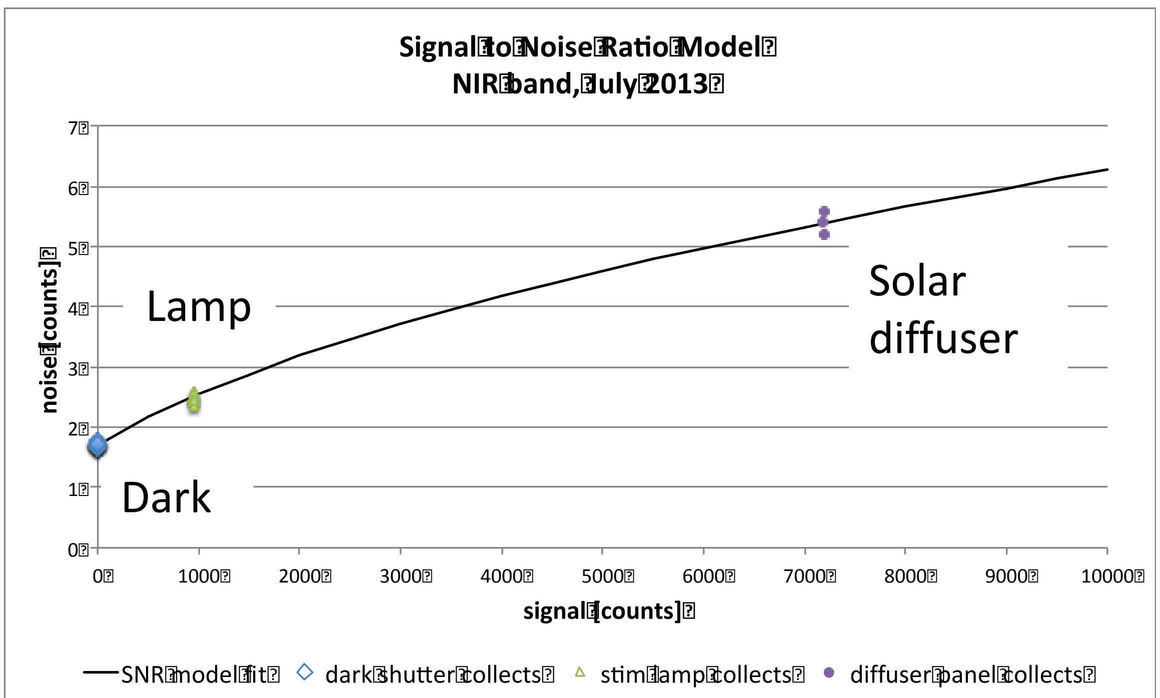
14 bit DN's

OLI Signal-to-Noise Ratio

- Noise model generated from shutter, lamp and diffuser data

$$s_i^2 = a + b * Q_i$$

  - Estimated monthly, once enough collects have been acquired

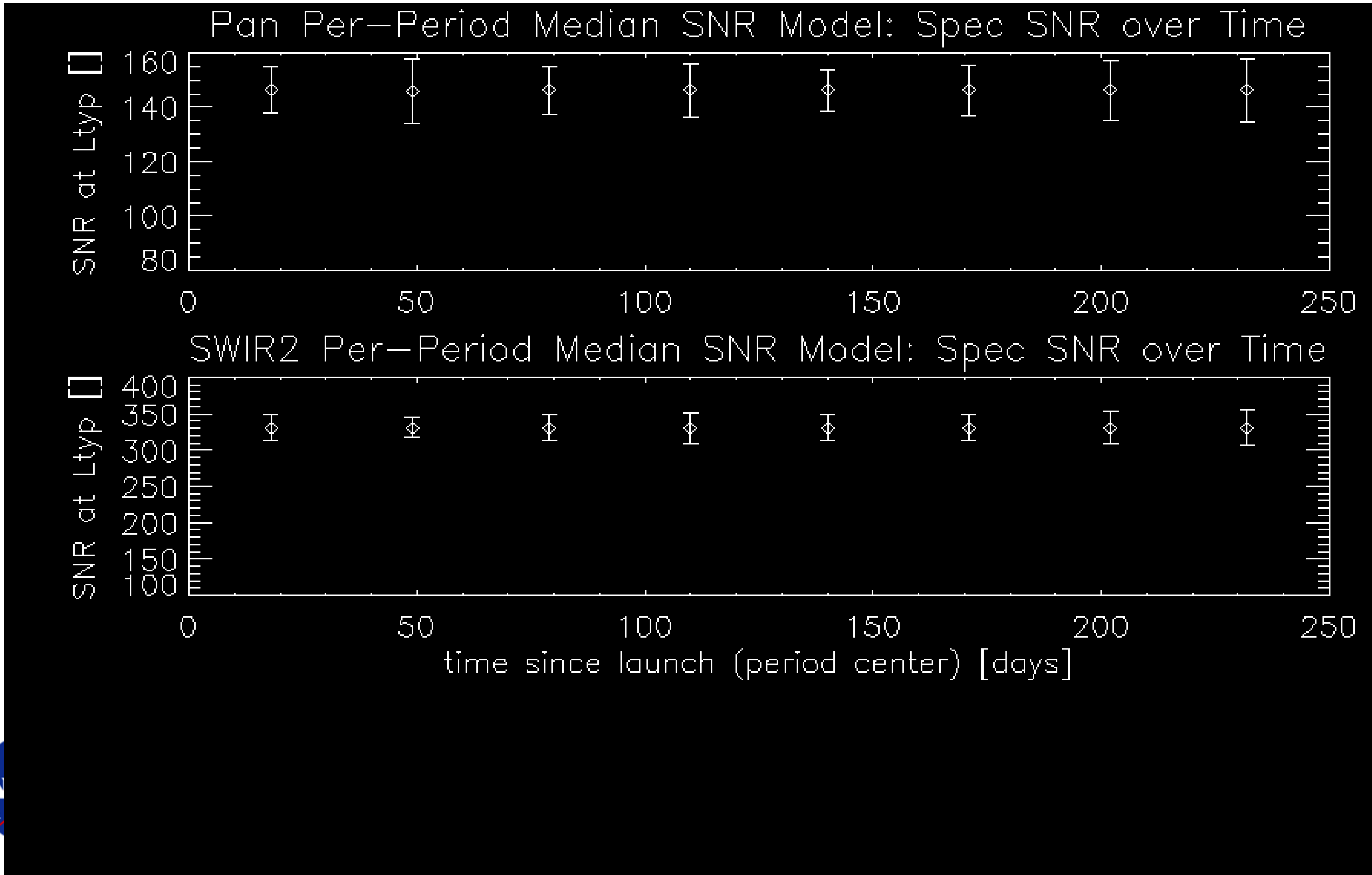


Signal-to-Noise Ratio

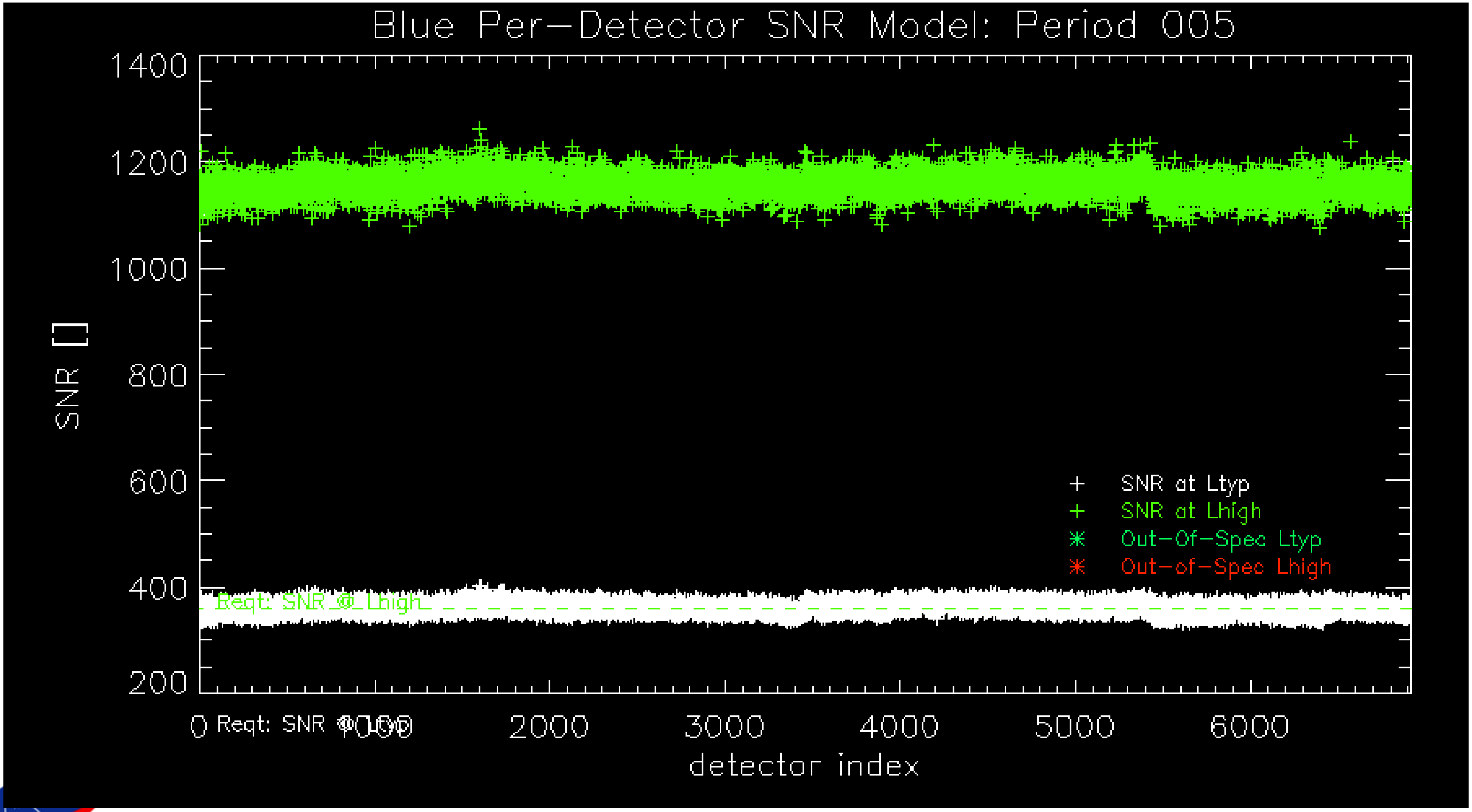
- The model is interpolated to a defined typical radiance level (L_{typ}), per-band
- OLI outperforms ETM+ by 6 – 12 x

Band	ETM + Band Number	OLI Band Number	"Typical" Radiance Level (Ltyp) [W/m^2 sr um]	ETM+ SNR (band average, low gain, at Ltyp)	OLI SNR (band median, at Ltyp)
CA	-	1	40	-	234
Blue	1	2	40	39	361
Green	2	3	30	37	299
Red	3	4	22	26	223
NIR	4	5	14	34	199
SWIR1	5	6	4	36	262
SWIR2	7	7	1.7	27	331
Pan	8	8	23	16	146
Cirrus	-	9	6	-	161

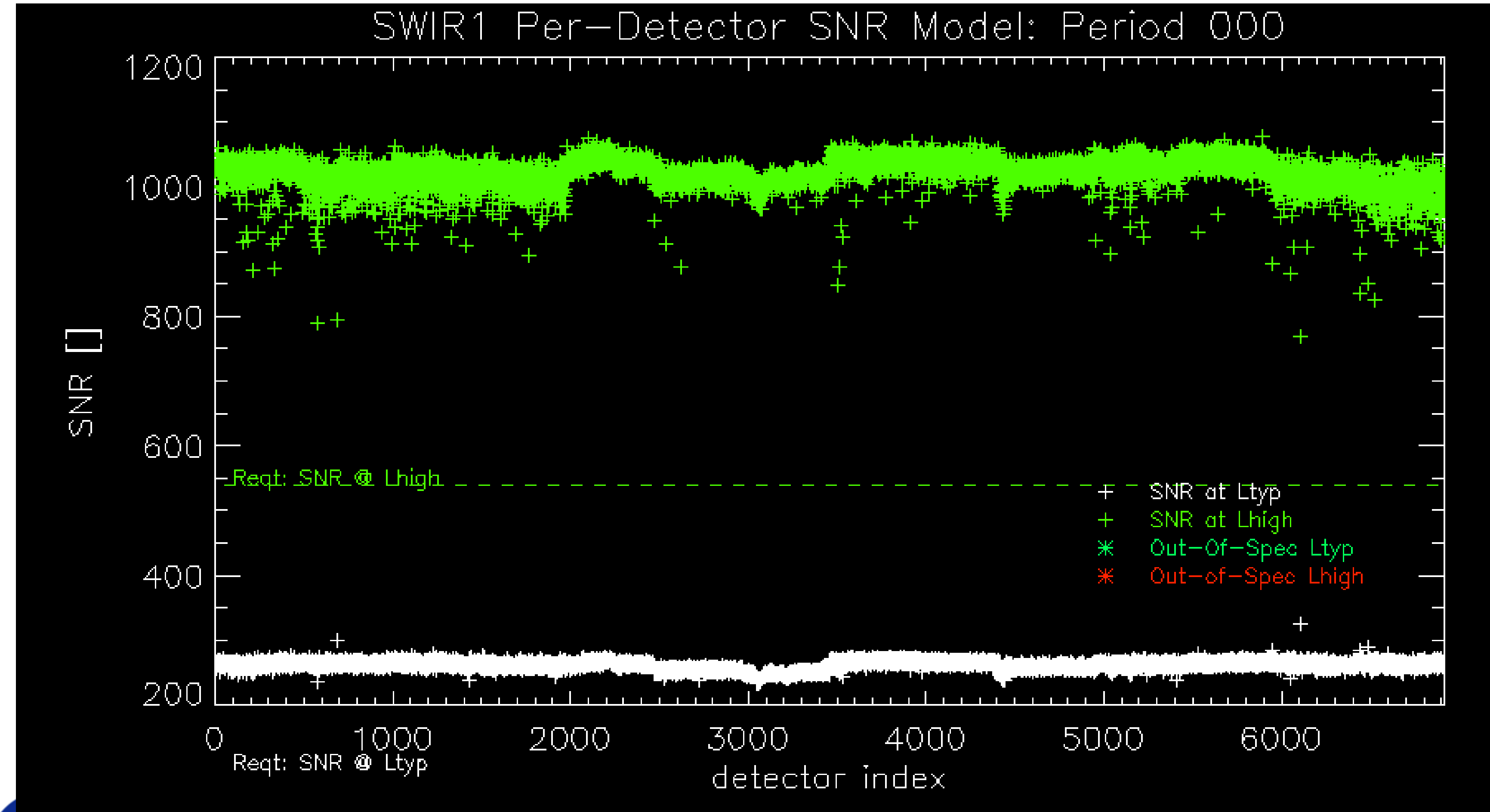
Noise Stability



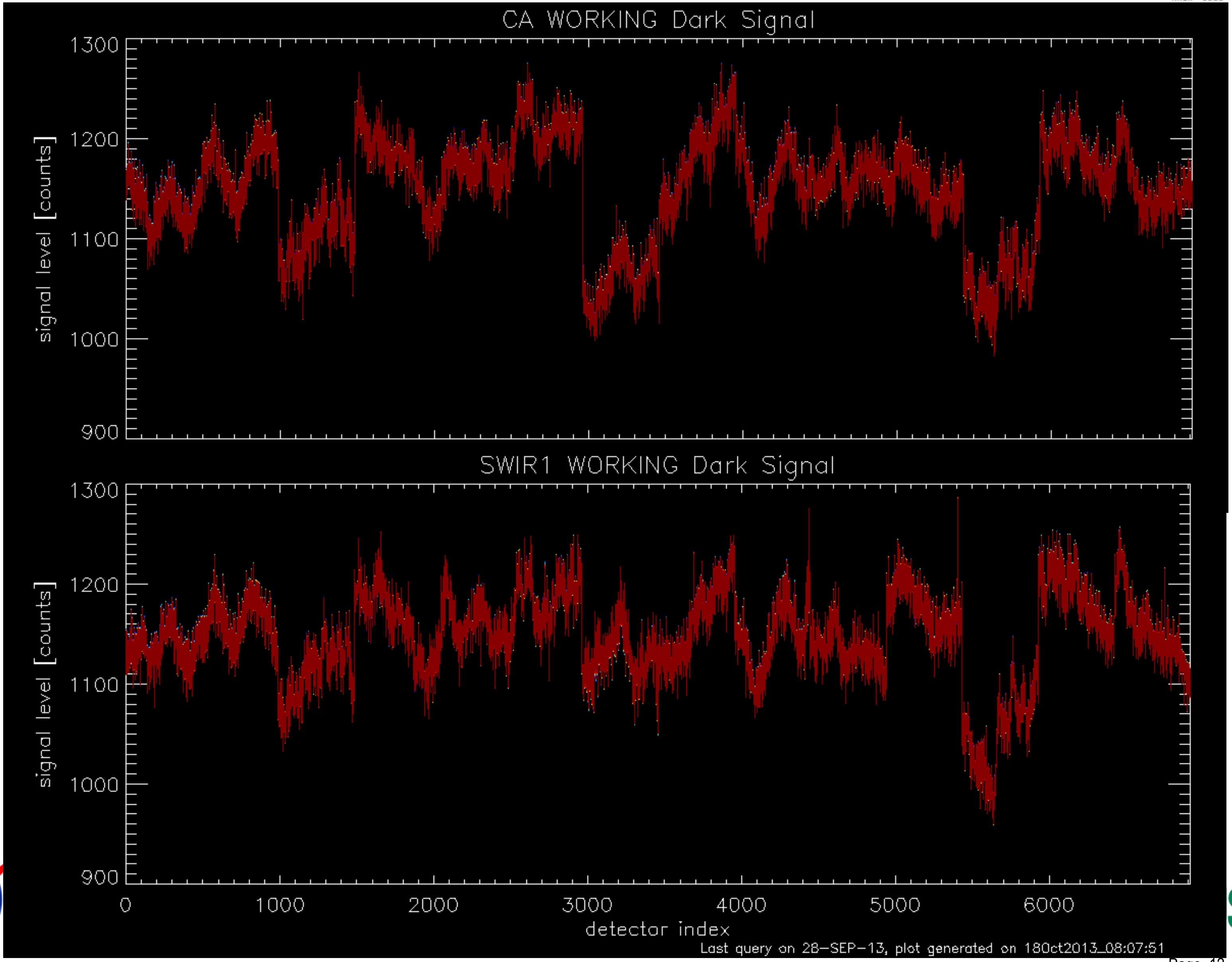
SNR Variability across FPA



SNR Variability across FPA

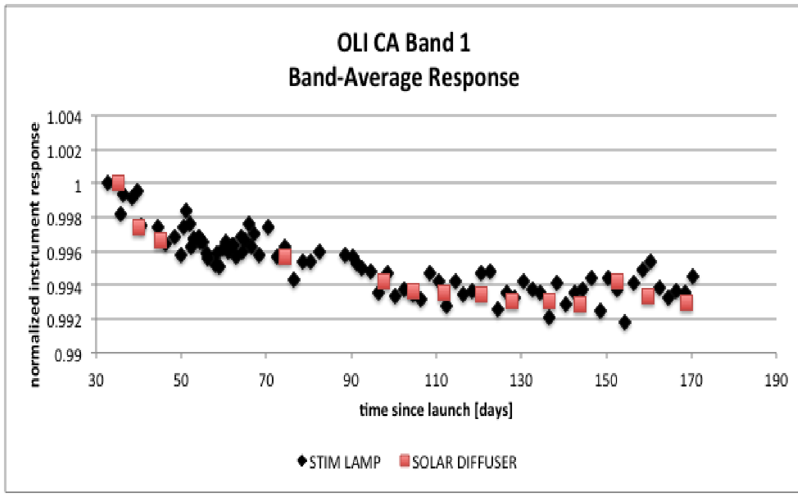


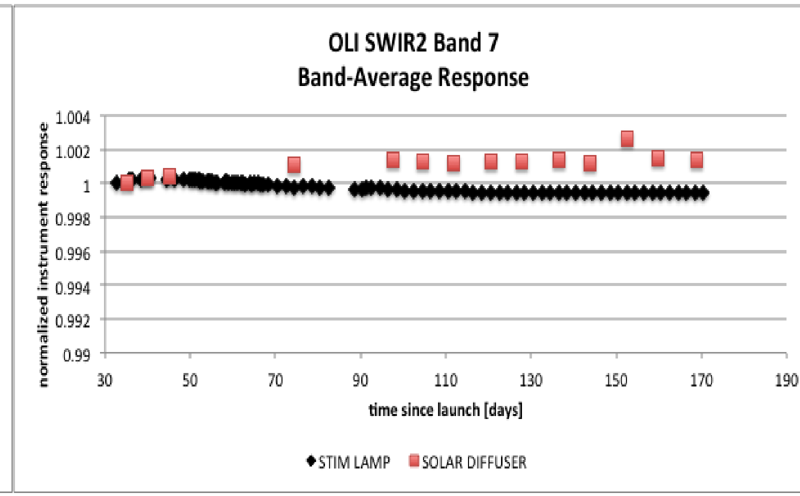
Stability - Dark Level



Radiometric Stability

- Characterized using response to lamp pairs, solar diffusers and lunar acquisitions +
- Monitor band-average response over time.



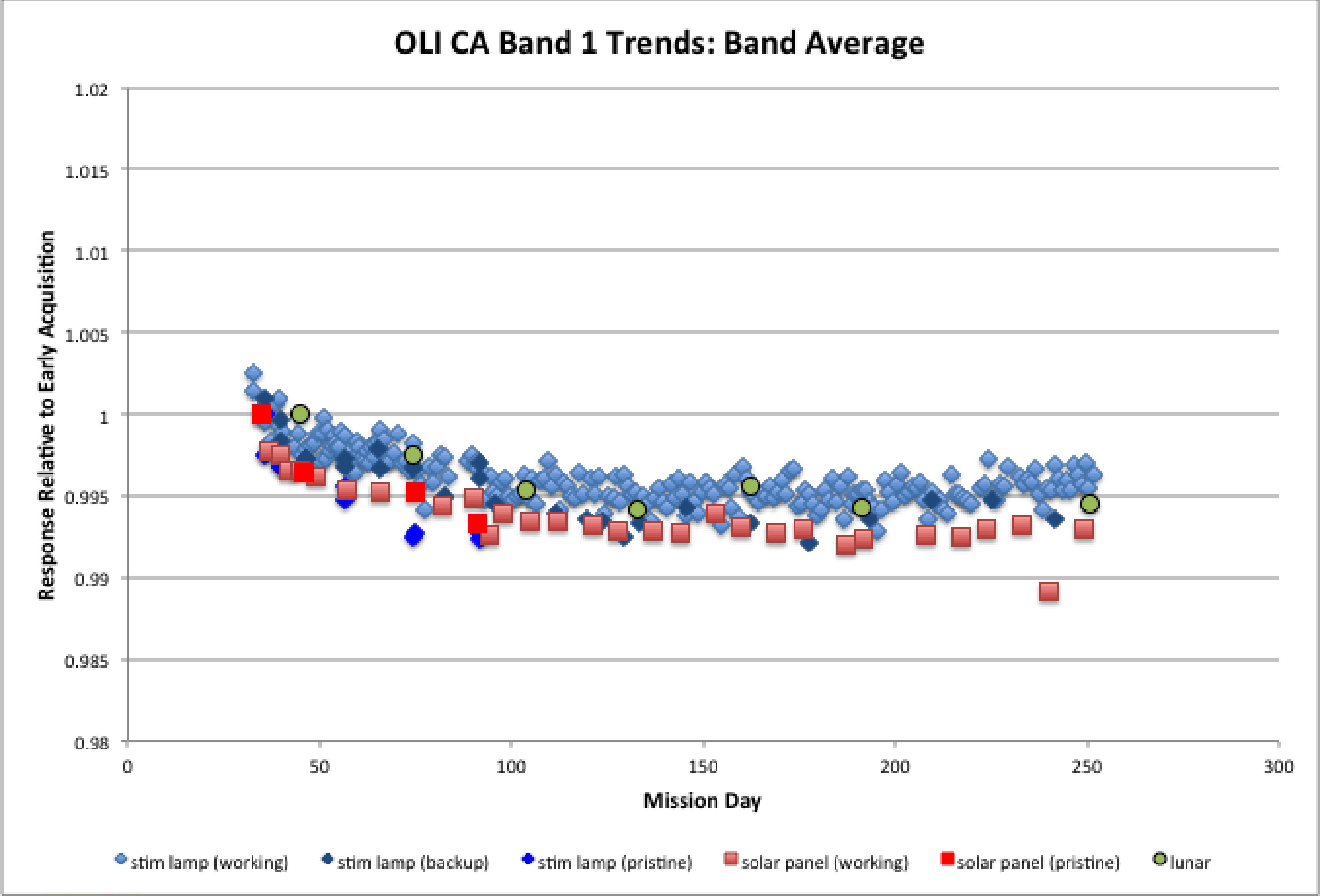


Radiometric Stability

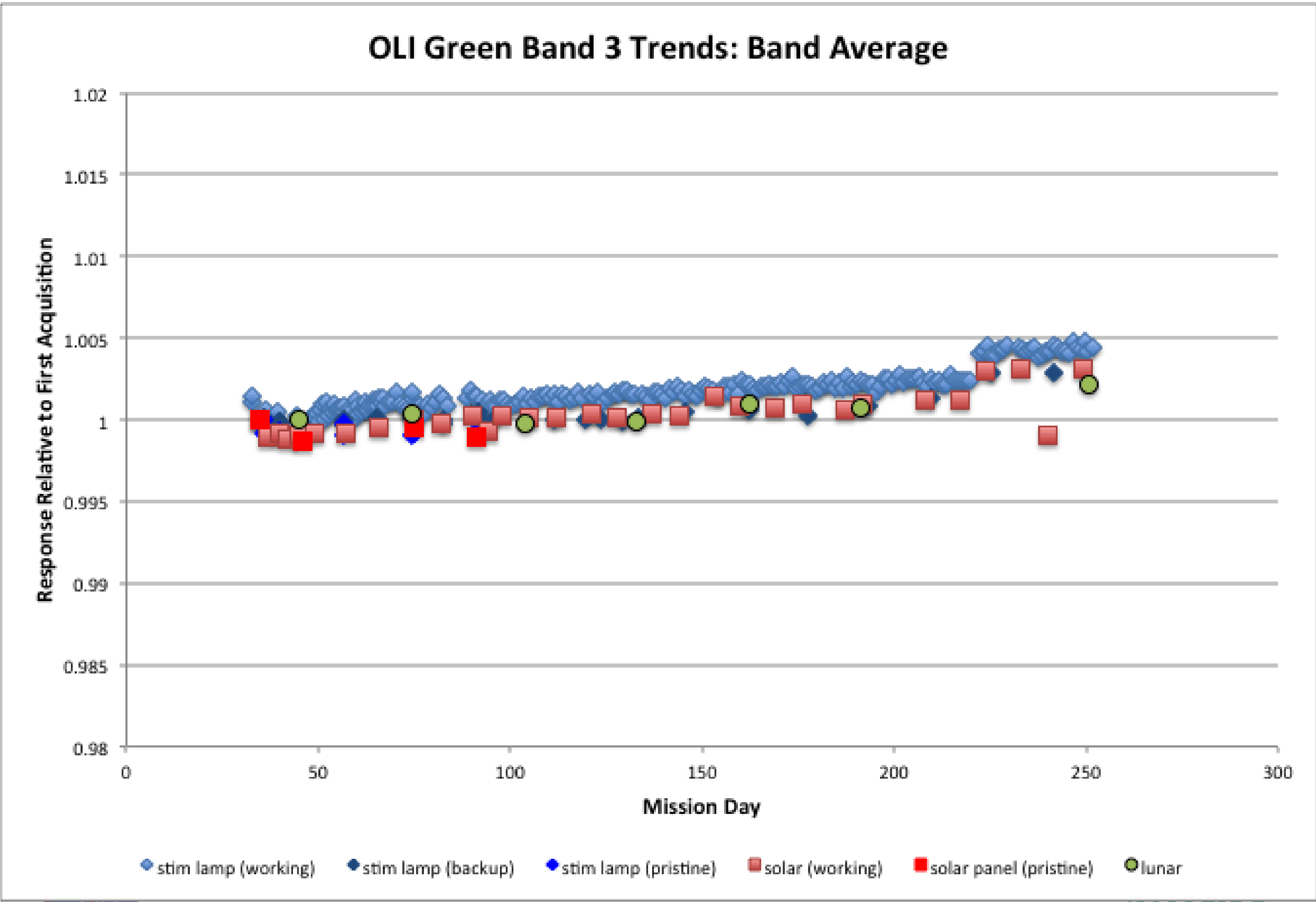
- Change to lamp response is generally echoed in the change to solar response, indicating the change is in the instrument, not the calibration device.

Band	Lamp Radiance [W/m^2 sr um]	Change relative to Lamp [%]	Diffuser Radiance [W/ m^2 sr um]	Change Relative to Diffuser [%]
CA	5.8	-0.62	500	-0.69
Blue	9.3	-0.30	517	-0.26
Green	18.6	0.10	476	0.11
Red	30.8	0.23	403	0.20
NIR	47.7	0.13	245	0.18
SWIR1	33.4	0.01	61.4	0.18
SWIR2	13.9	-0.05	19.4	0.14
Pan	22.6	0.03	455	0.17
Cirrus	42.8	0.03	94.0	0.10

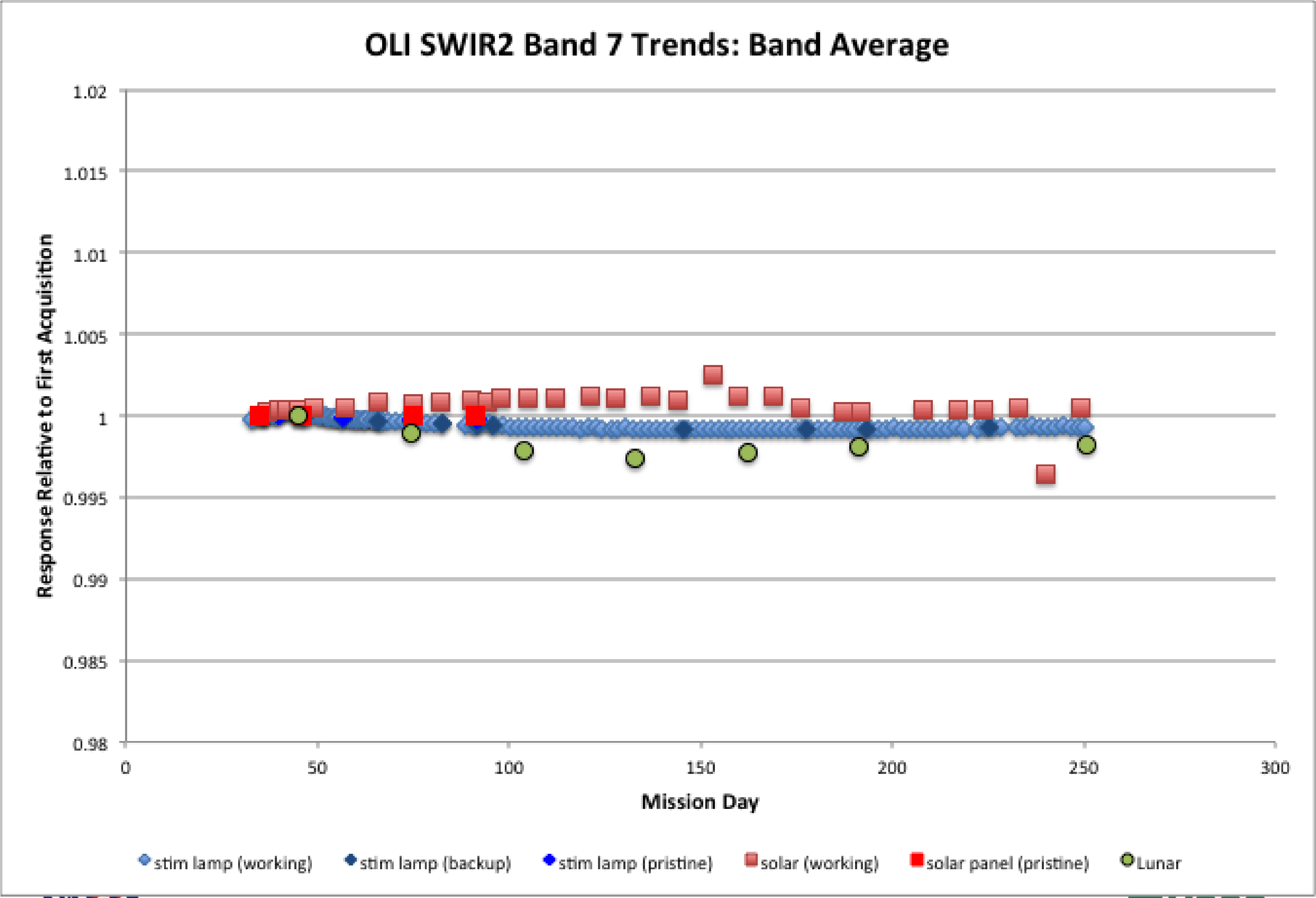
As of mid August 2013


OLI CA Band 1 Trends: Band Average
Response Relative to Early Acquisition
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
0.98
0
50
100
150
200
250
300
Mission Day
stim lamp (working)
stim lamp (backup)
stim lamp (pristine)
solar panel (working)
solar panel (pristine)
lunar

Rawer data



OLI Green Band 3 Trends: Band Average
Response Relative to First Acquisition
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
0.98
0
50
100
150
200
250
300
Mission Day
stim lamp (working)
stim lamp (backup)
stim lamp (pristine)
solar (working)
solar panel (pristine)
lunar



OLI SWIR2 Band 7 Trends: Band Average
Response Relative to First Acquisition
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
0.98
0
50
100
150
200
250
300
Mission Day
stim lamp (working)
stim lamp (backup)
stim lamp (pristine)
solar (working)
solar panel (pristine)
Lunar

Stability – Ongoing Studies

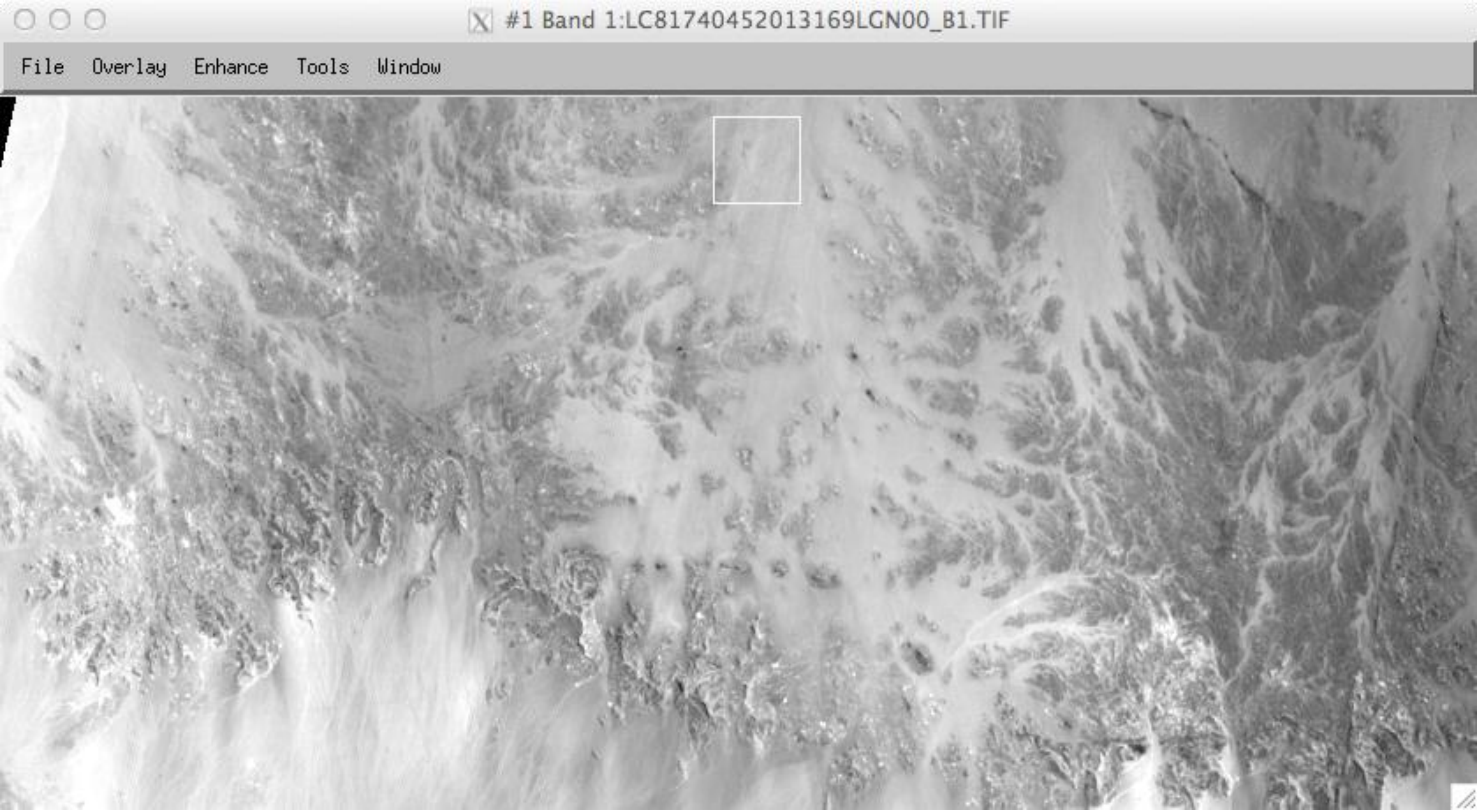
- Improving precision of Lunar calibration
- Examining repeatability of pointing for solar diffuser measurements
- Examining stability of lamps, photodiodes, temperatures and telemetry

Uniformity

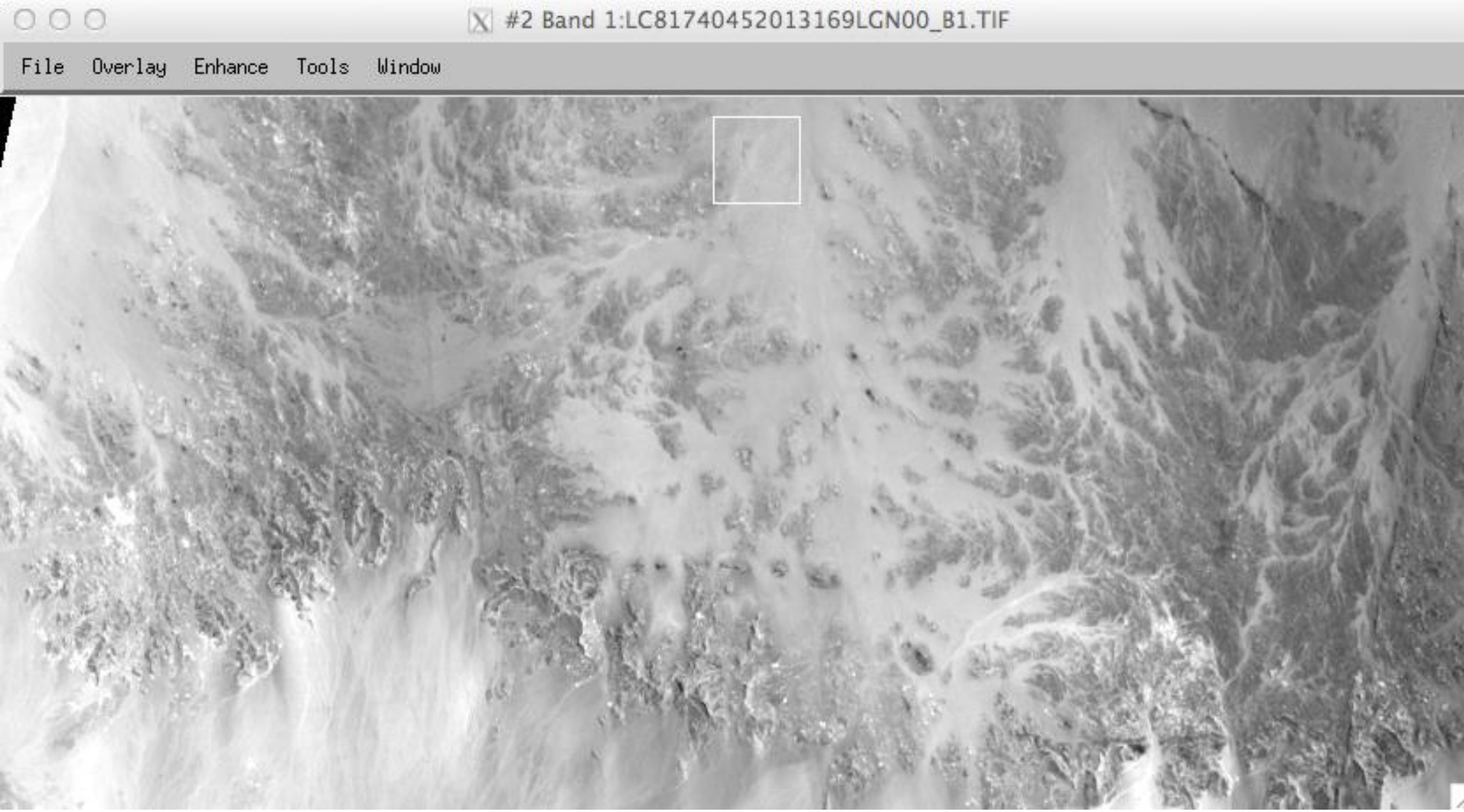
- Challenge due to the large numbers of detectors in each band, high precision of data and low level non-linearity in the system.
- Various metrics attempt to capture individual detector variation (streaking), groups of detectors/FPM's (banding) and full field of view variability
- Used pre-launch characterization for initial processing
  - Processed scenes generally visually very good
  - On-orbit images have some streaking and banding.
  - Magnitude of non-uniformity generally <0.5%
  - Visible in uniform scenes, particularly CA band, SWIR bands

Uniformity

- Two updates to the calibration parameters have decreased striping and banding.
- Aug 9, 2013: Linearization function update
  - Based on reanalysis of prelaunch test data
  - Improves SWIR bands
- Aug 21, 2013: Relative Gain update
  - Based on on-orbit solar diffuser data
- Upcoming: Correcting edge detector relative gains

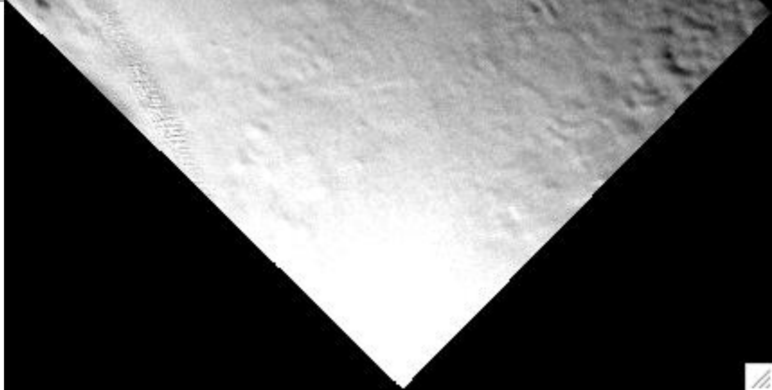


Egypt: DOY 169, 174/45
CA band, FPM1+
Original calibration parameters



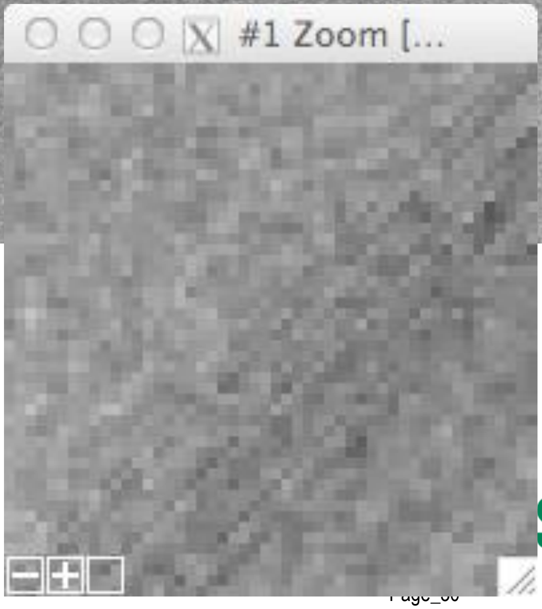
Egypt: DOY 169, 174/45
CA band, FPM1+
Updated calibration parameters

Greenland: DOY 118, 16/4
Green band, FPM3
Original calibration parameters

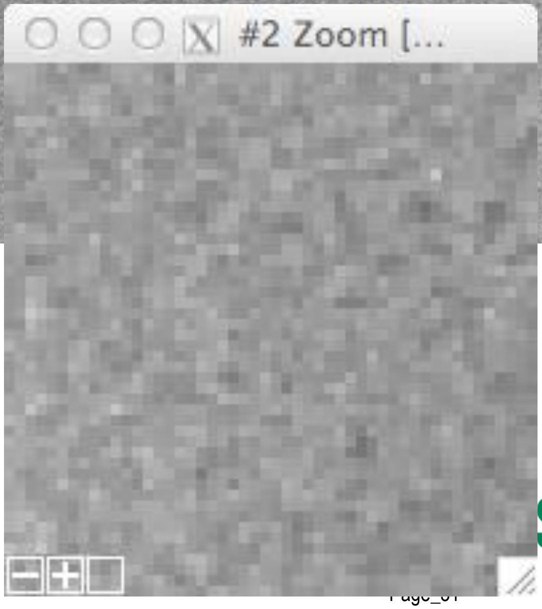


Greenland: DOY 118, 16/4
Green band, FPM3
Updated calibration parameters

Linearity feature,
not relative gain



Greenland: DOY 118, 16/4
SWIR1 band, FPM9
Original calibration parameters



Greenland: DOY 118, 16/4
SWIR1 band, FPM9
Updated calibration parameters

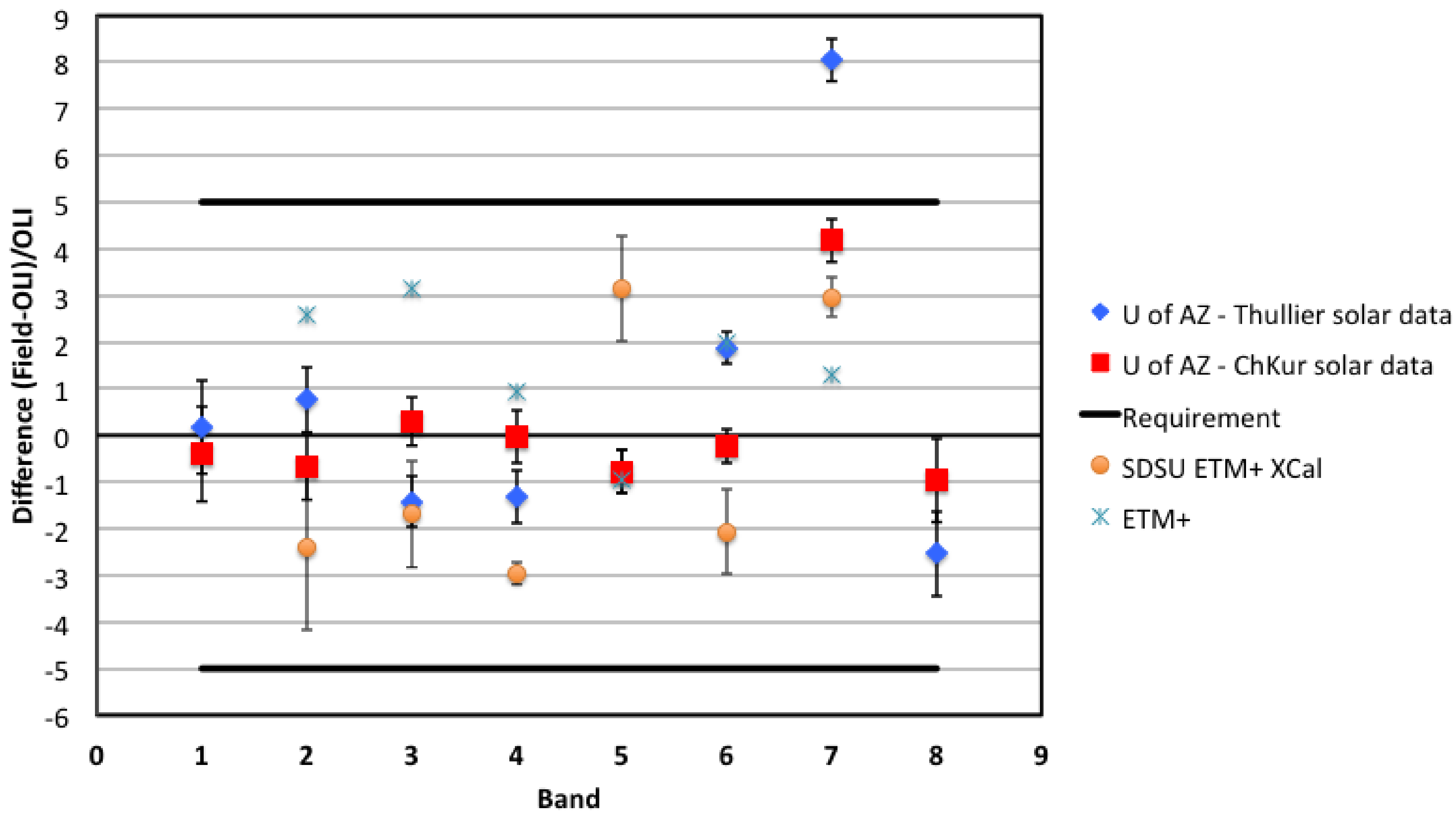
Uniformity

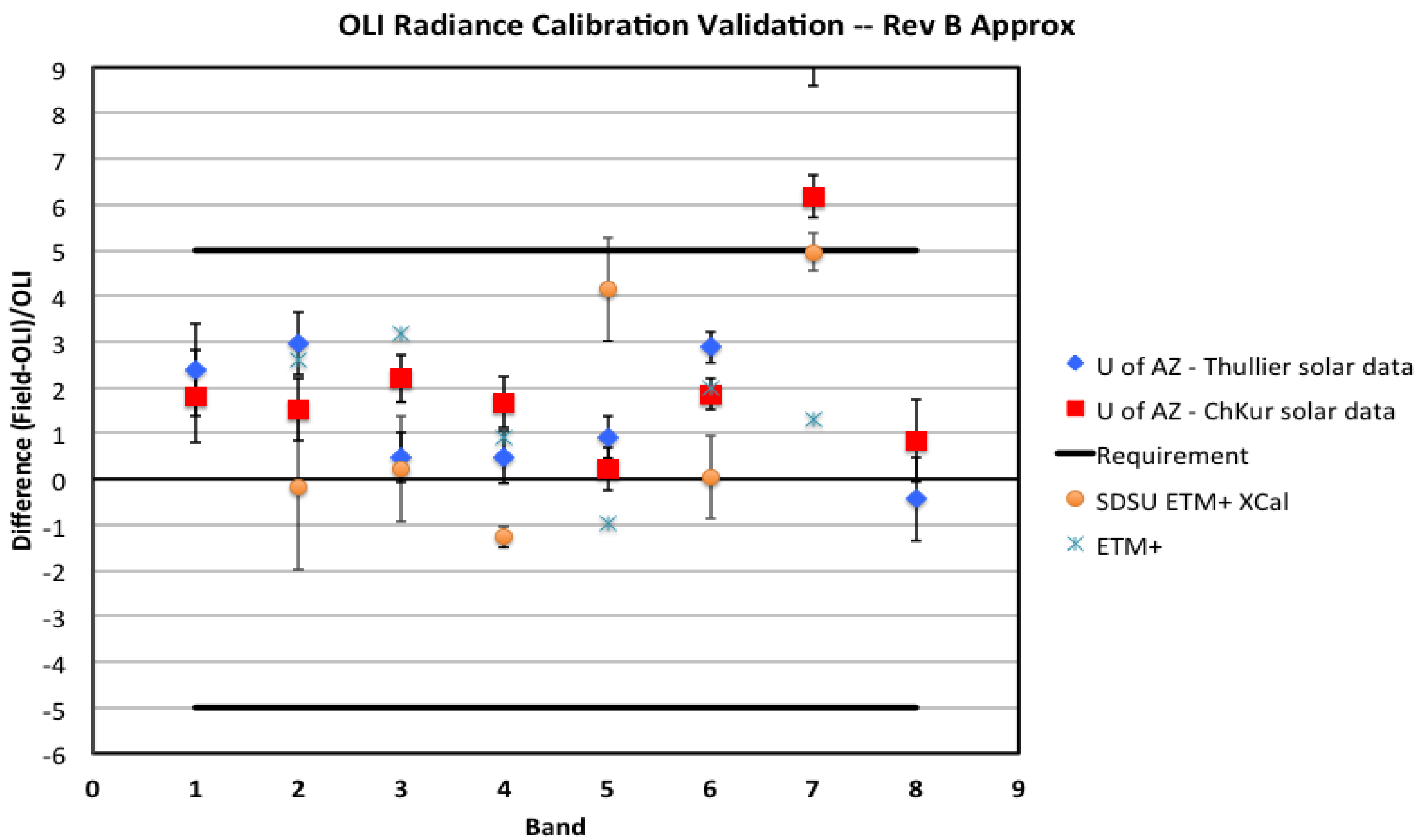
- Discontinuities still exist at the boundaries between adjacent FPMs
  - In some cases, as large as 1%
- Result of some combination of
  - Slight view angle differences between odd and even focal plane modules in conjunction with illumination angles and bidirectional reflectance
  - Errors in pre-launch relative calibration
  - Errors in pre-launch linearity characterization
  - Changes in relative calibration since launch
- Studies are ongoing.

Upcoming Changes/Ongoing Studies

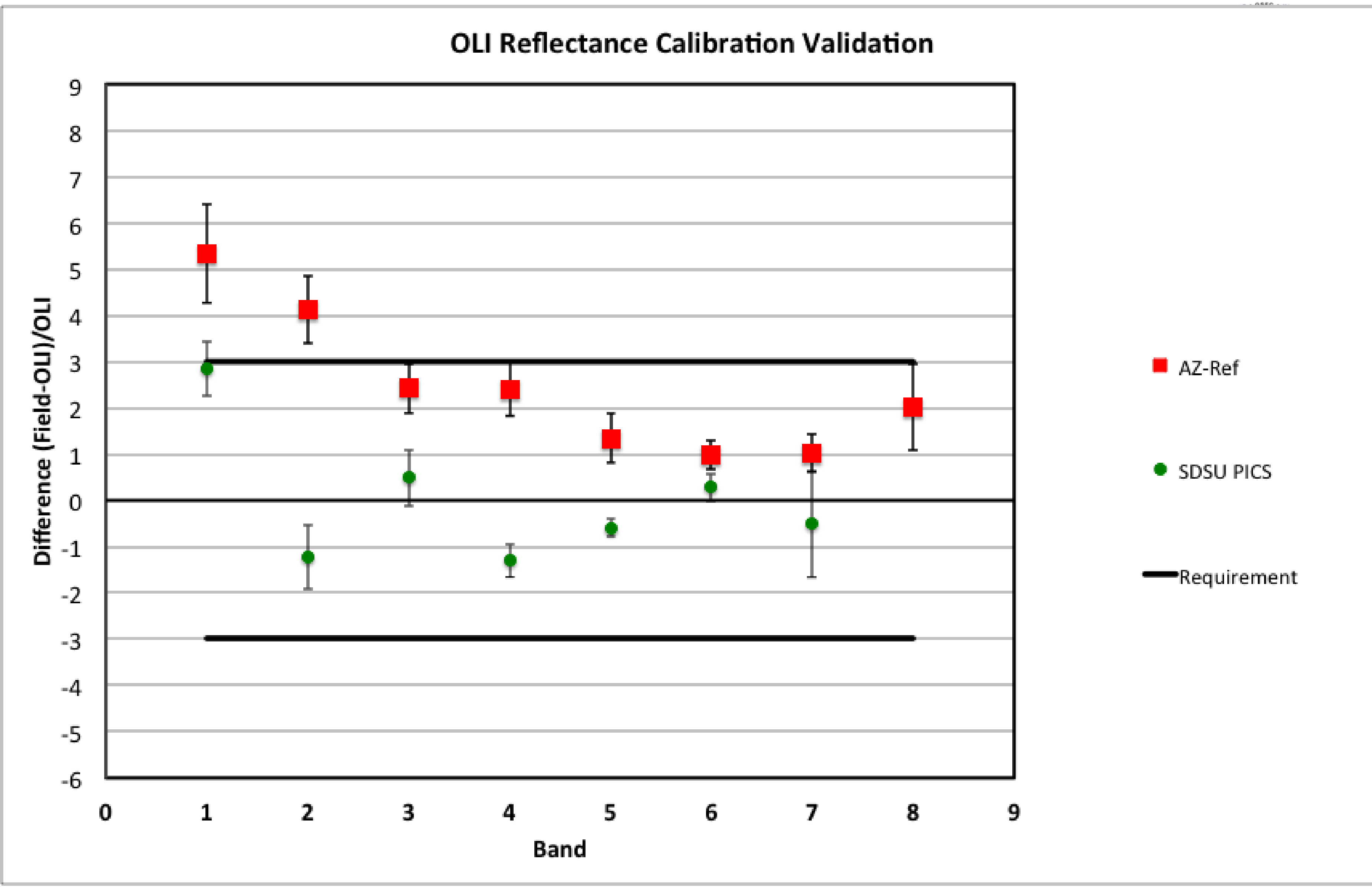
- Changing to pure Look-up-table linearization procedure
  - Increased flexibility
  - Should improve low radiance level non-uniformity
- Reexamining linearization assumptions/procedure
  - Parsing detector and electronic linearity to allow updating only electronic linearity on orbit
  - Special solar diffuser collect during solar eclipse
- Reexamining diffuser reflectance “non-uniformity” in diffuser data processing
  - Initially based on heliostat data
  - Testing U of A measurements as alternative
- Side slither, scene statistics, overlap statistics
  - Alternates to solar diffuser

OLI Radiance Calibration Validation





OLI Radiance Calibration Validation -- Rev B Approx
Difference (Field-OLI)/OLI
Band
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
1
2
3
4
5
6
7
8
9
U of AZ - Thullier solar data
U of AZ - ChKur solar data
Requirement
SDSU ETM+ XCal
ETM+

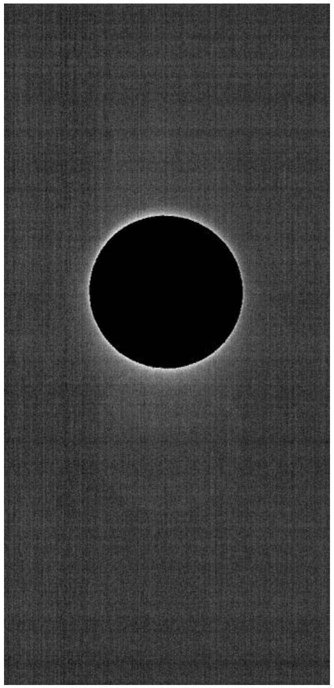

OLI Reflectance Calibration Validation
Difference (Field-OLI)/OLI
Band
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
1
2
3
4
5
6
7
8
9
AZ-Ref
SDSU PICS
Requirement

Absolute Calibration Investigations/Updates

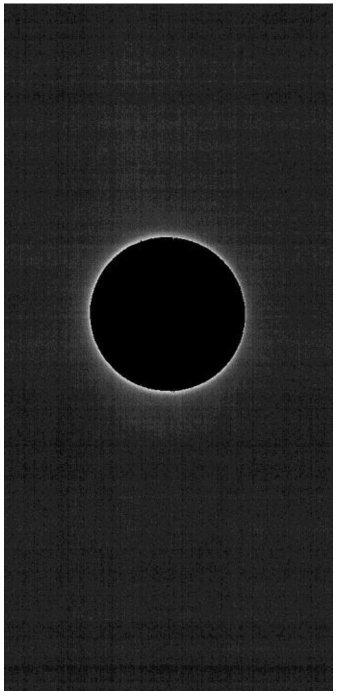
- Upcoming- correcting cirrus band reflectance calibration by ~7%
- Reviewing prelaunch radiance calibration process (for SWIR-2 band in particular) and transfer to orbit test
- Reviewing reflectance calibration

OLI Artifacts

- No coherent (a.k.a. pattern noise) observed
- Spatial artifacts (i.e., ghosting, crosstalk) << requirements



OLI Band 9 (Cirrus)



OLI Band 6 (SWIR 1)

very weak ghost/ halo

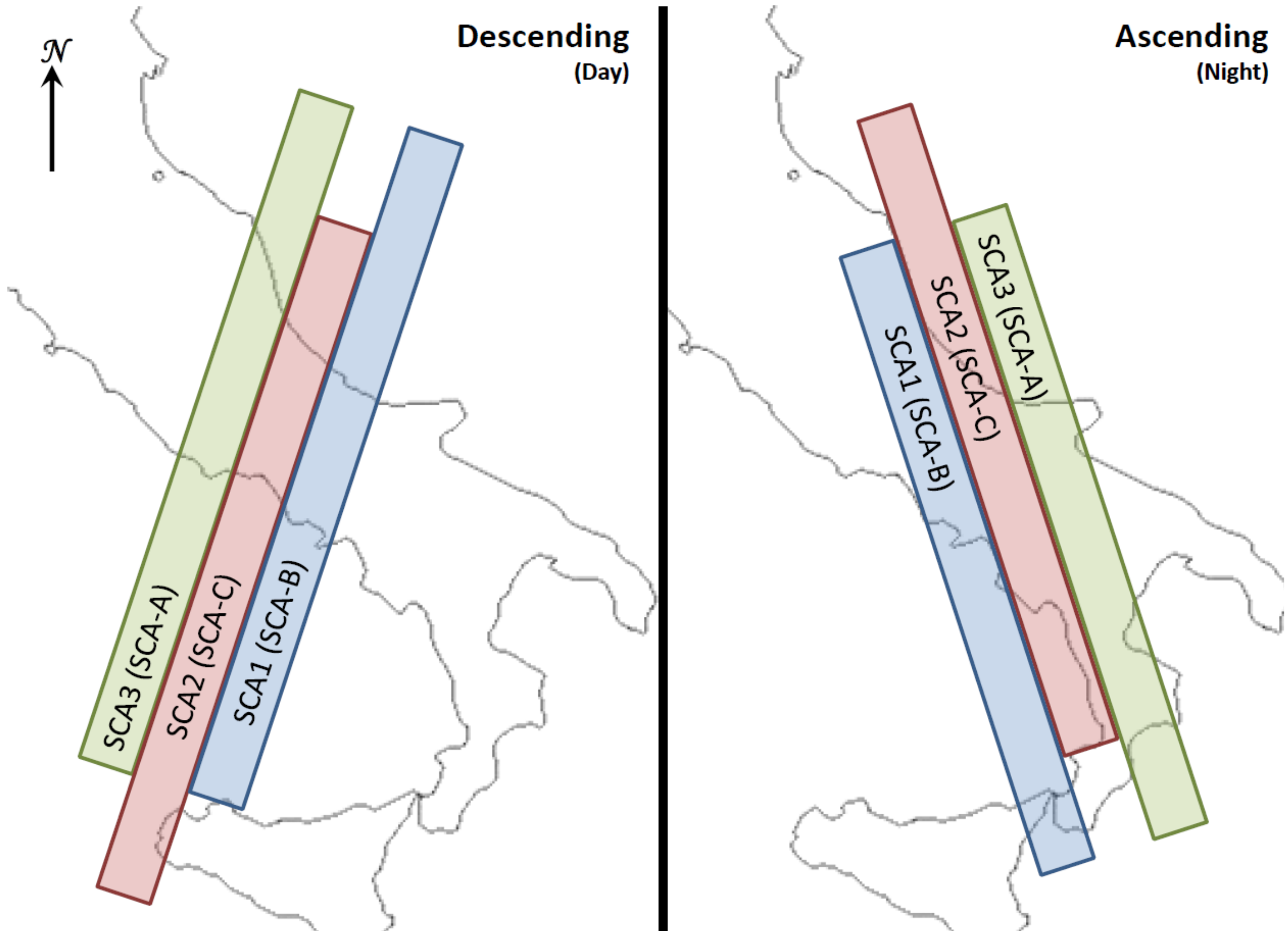
OLI Radiometry Summary

- OLI performing well since launch
- Daily acquisitions of the working lamp pair and acquisition of the working solar diffuser every eight days provide useful characterization of OLI
- OLI outperforms ETM+ in SNR by an order of magnitude
- Stability exceeding requirements; no evidence of significant contamination/degradation of instrument or calibrators
- Uniformity has been improved recently, reducing striping by half
  - Discontinuities at FPM boundaries still remain
- Absolute Radiance Calibration generally within ±2% of vicarious measurements – SWIR2 an outlier at 5%
- Absolute Reflectance Calibration generally within ±2% of vicarious measurements – CA and Blue at 4-5%

TIRS

- Noise
- Stability
  - Transfer to Orbit
  - Over Acquisition Interval
  - Over Mission
- Relative Calibration
- Absolute Calibration
- Artifacts
- Summary

Focal Plane Layout



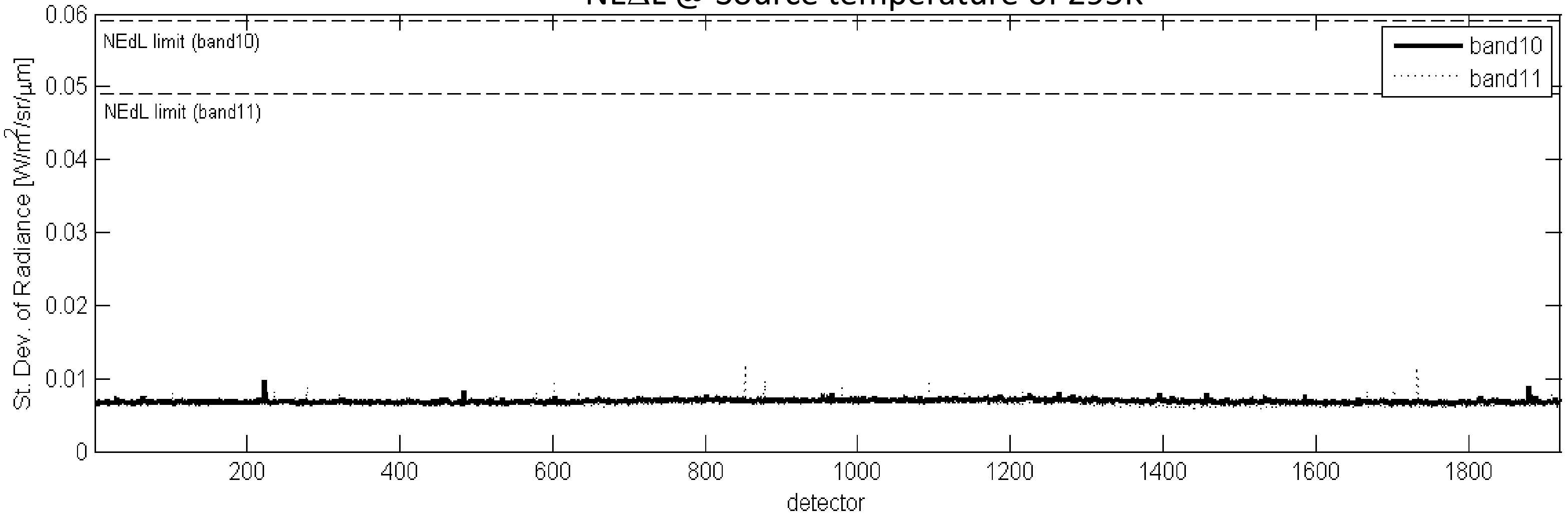
(Roughly to Scale)

TIRS On-Orbit Performance: Noise

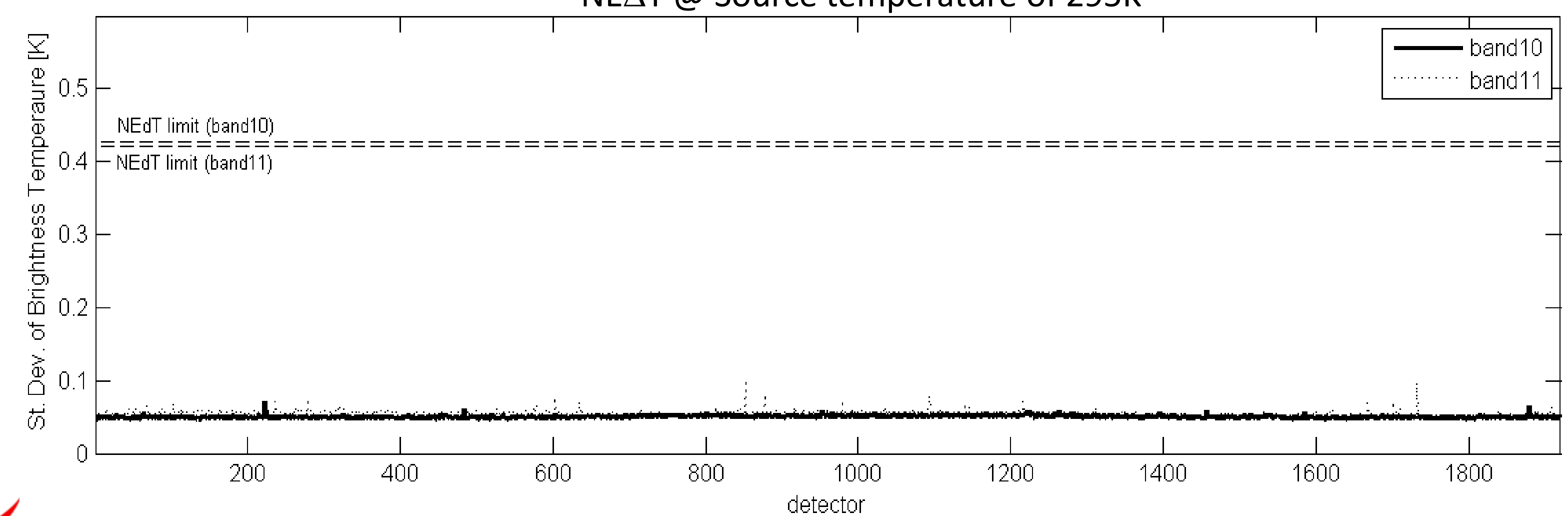
- Variation of signal to a constant source
- Noise expressed as a variation in radiance: NEΔL
- Noise expressed as a variation in brightness temperature: NEΔT
- View OBC at fixed temperature for one minute (4200 frames)
  - Subtract background from each frame
  - convert each frame to radiance -> take standard deviation of each detector as the NEΔL
  - convert each frame to temperature -> take standard deviation of each detector as NEΔT

TIRS On-Orbit Performance: Noise (2)

NEΔL @ Source temperature of 295K



NEΔT @ Source temperature of 295K

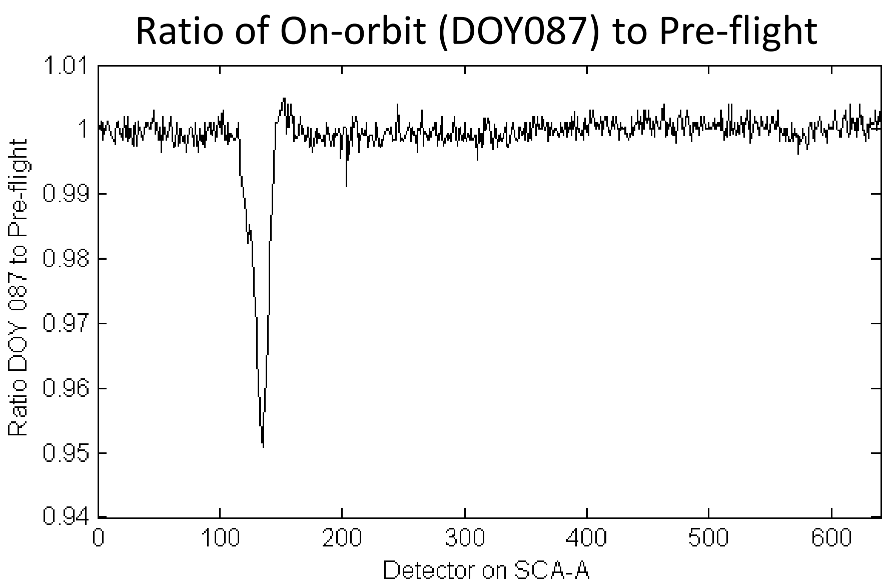


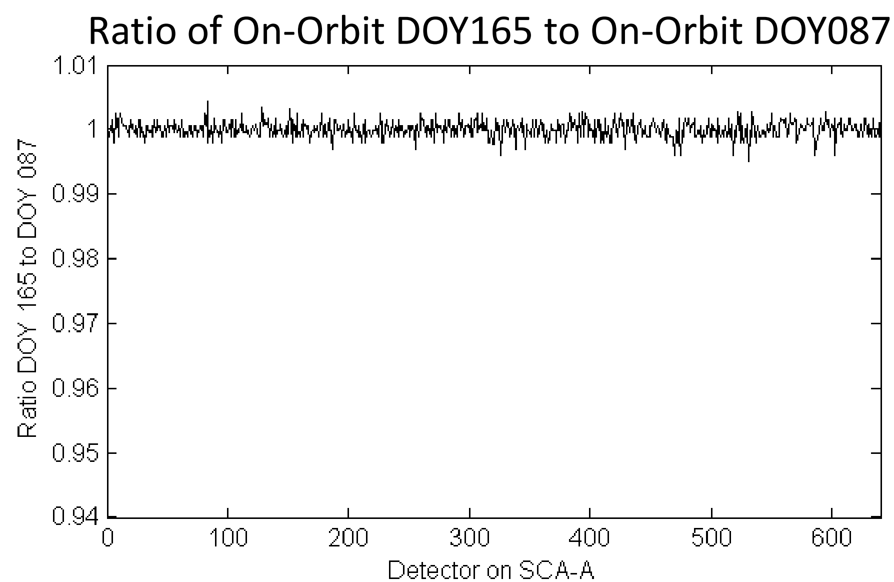
- TIRS meets NEΔL and NEΔT requirements for source @ 295K by about a factor of 8; Factor of ~3 better than ETM+ (similar results for other temperatures)

TIRS Stability: Transfer to Orbit

- Relative ratio of On-orbit to Pre-flight OBC signal illustrates the effect of the contamination in TIRS 2 (band 11)

- Relative ratio of the OBC signal of DOY 165 to DOY 087 illustrates that the contamination has been constant over that time



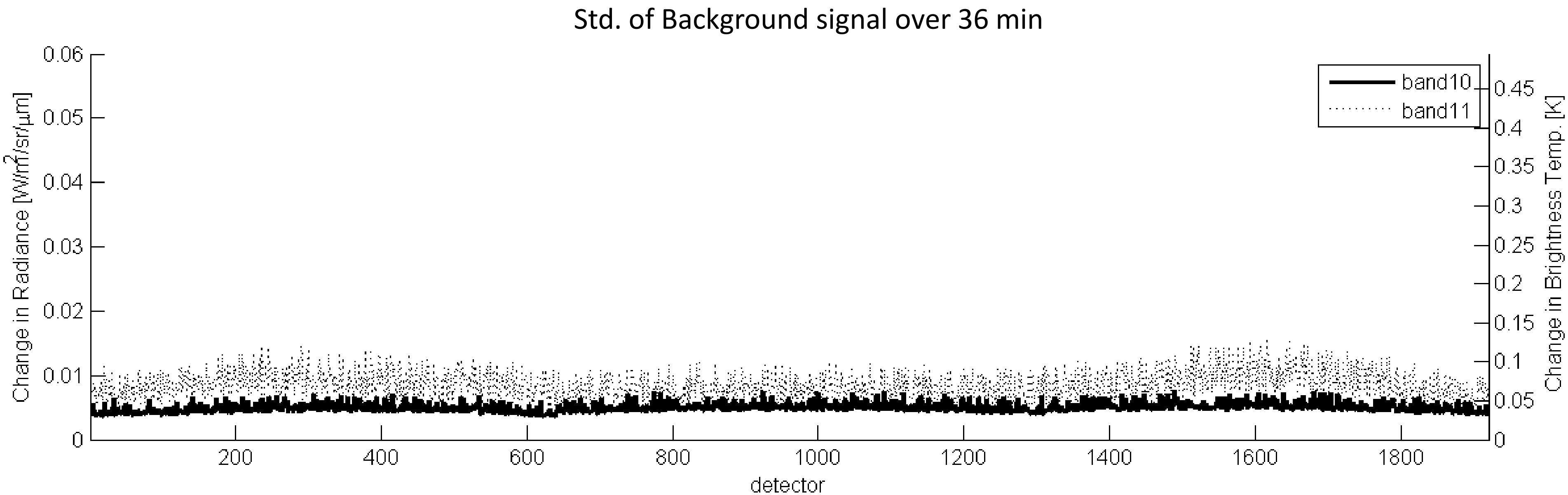


- Will be continuously monitored throughout operations

TIRS On-Orbit Performance: Background Stability over Interval

• Observed the variation (std.) of the background signal over the same 36 min collect.

• Express the variation in background as a change in radiance @ 300 K and as a change in brightness temperature @ 300 K

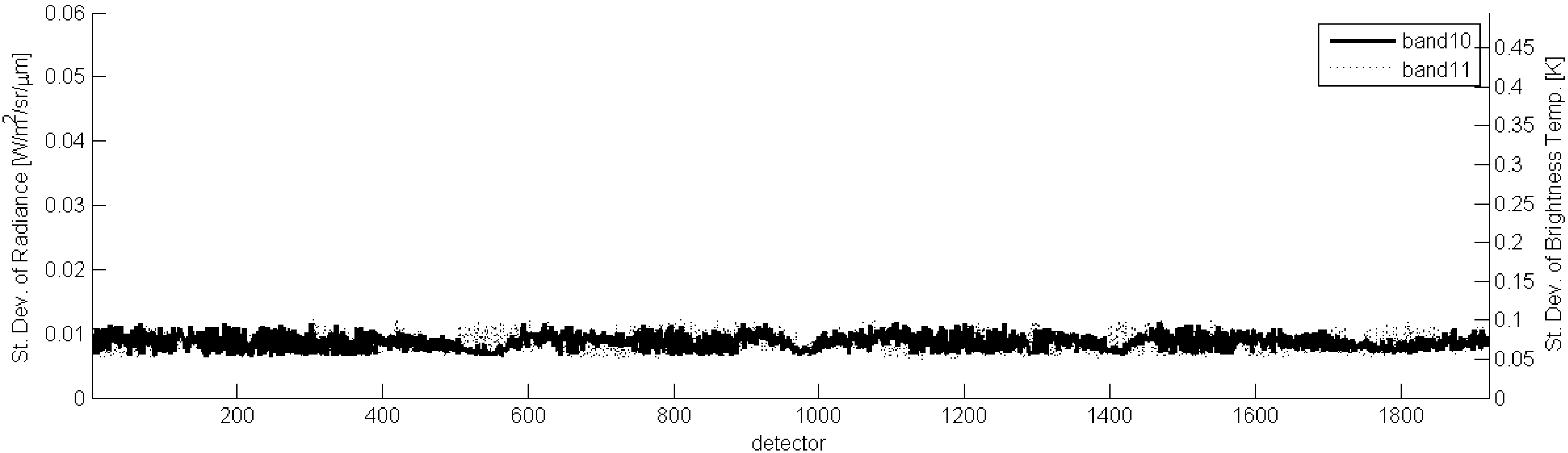


• One-sigma variation of ~0.01 radiance units or 0.1 K implies stable background.

TIRS On-Orbit Performance: OBC Response Stability over Interval

- Collected image data of OBC @ 270 K for 36 continuous minutes.
- Observed the variation (standard deviation) of the radiance over that time period.

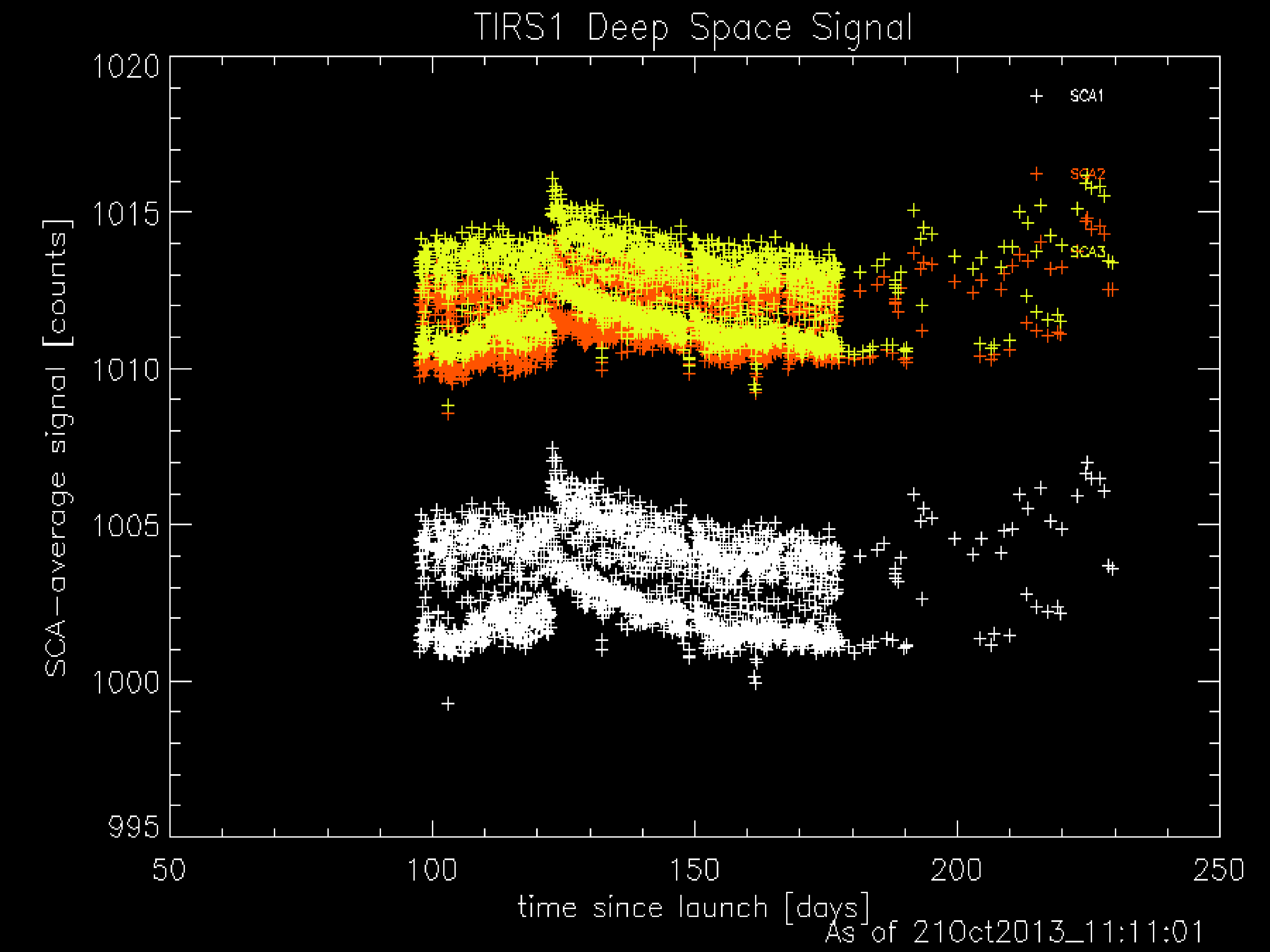
Std. of OBC signal over 36 min

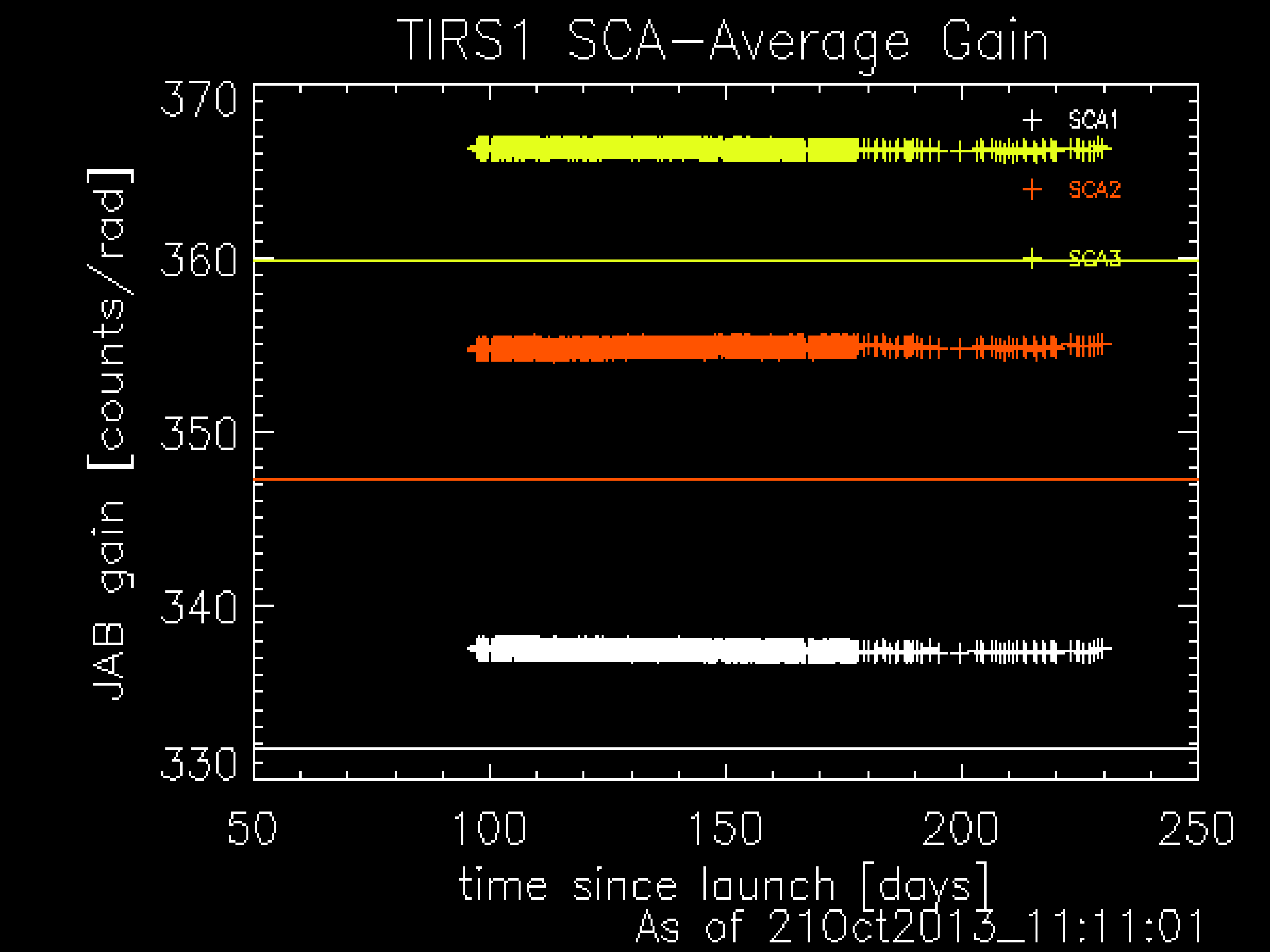


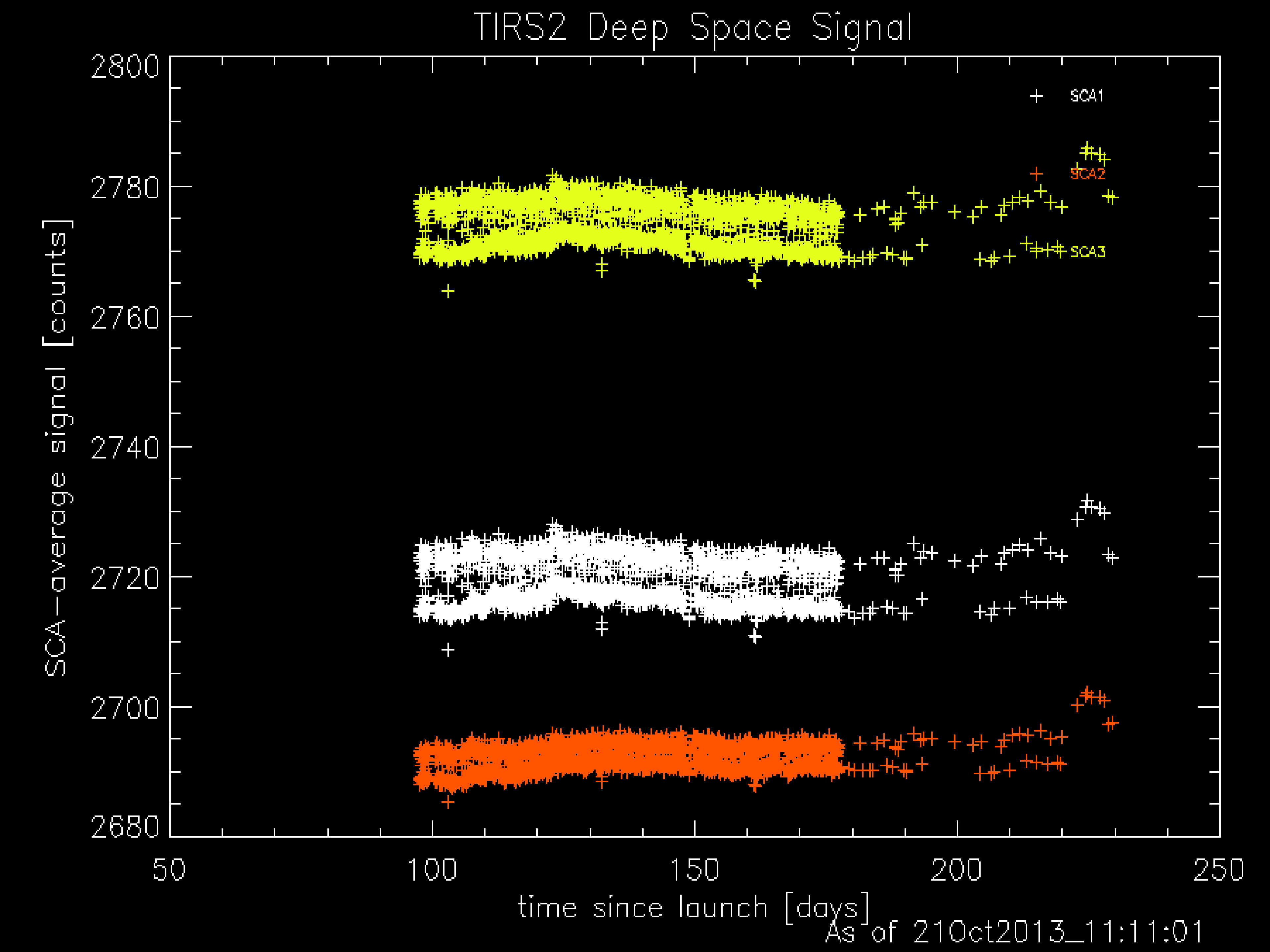
- One-sigma variation is approx. 0.2% of the average radiance
  - TIRS requirement states that this variation should be less than 0.7%
  - Only slightly higher than within scene noise

TIRS On-Orbit Performance: Stability over mission life

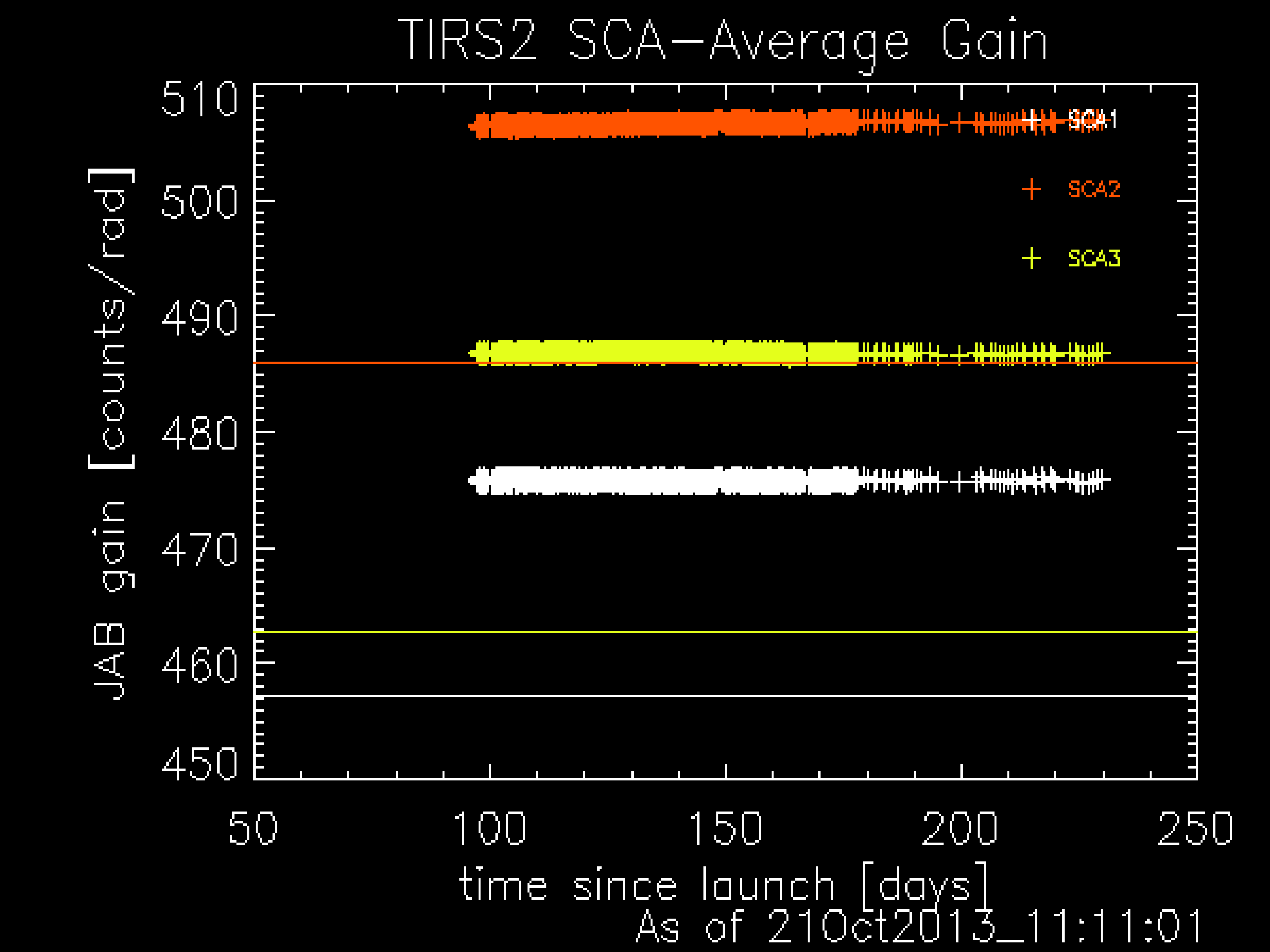
- Calibration collects before and after Earth imaging (typically two collects/orbit; 14.5 orbits/day)
- Means and Standard deviations of each collect stored in Image Assessment System (IAS) database
- No long term degradation/contamination evident
  - Band 10 Gain Trends
    - - 0.06%/100 days SCA 1
    - + 0.05%/100 days SCA 2
    - - 0.04%/100 days SCA 3
  - Band 11 Gain Trends
    - - 0.01%/100 days SCA 1
    - + 0.08%/100 days SCA 2
    - - 0.02%/100 days SCA 3


TIRS1 Deep Space Signal
SCA-average signal [counts]
time since launch [days]
SCA1
SCA2
SCA3
1020
1015
1010
1005
1000
995
50
100
150
200
250
As of 21Oct2013_11:11:01


TIRS1 SCA-Average Gain
SCA1
SCA2
SCA3
370
360
350
340
330
50
100
150
200
250
JAB gain [counts/rad]
time since launch [days]
As of 21Oct2013_11:11:01



TIRS2 Deep Space Signal
SCA1
SCA2
SCA3
SCA-average signal [counts]
2680
2700
2720
2740
2760
2780
2800
50
100
150
200
250
time since launch [days]
As of 21Oct2013_11:11:01

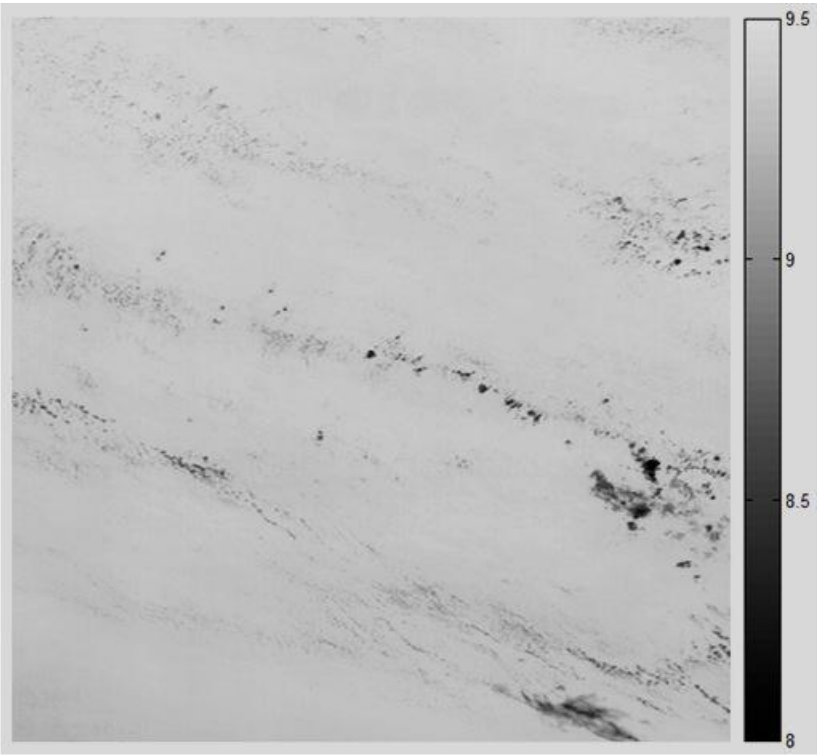

TIRS2 SCA-Average Gain
JAB gain [counts/rad]
510
500
490
480
470
460
450
SCA1
SCA2
SCA3
50
100
150
200
250
time since launch [days]
As of 21Oct2013_11:11:01

TIRS: On-Orbit Performance: Spatial Uniformity

- Banding/streaking requirements meant to assess the spatial uniformity across the field of view for an Earth scene

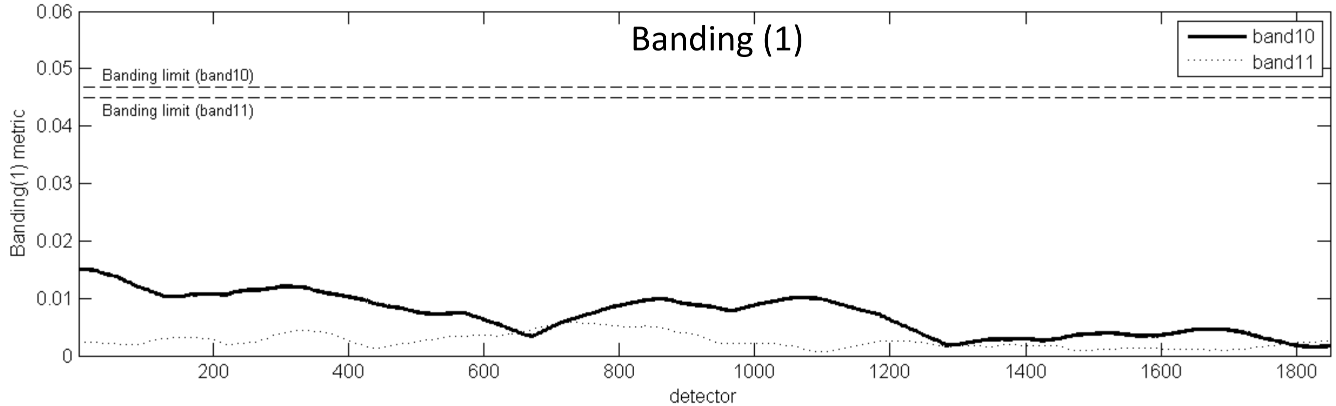
- Metrics very dependent on the scene

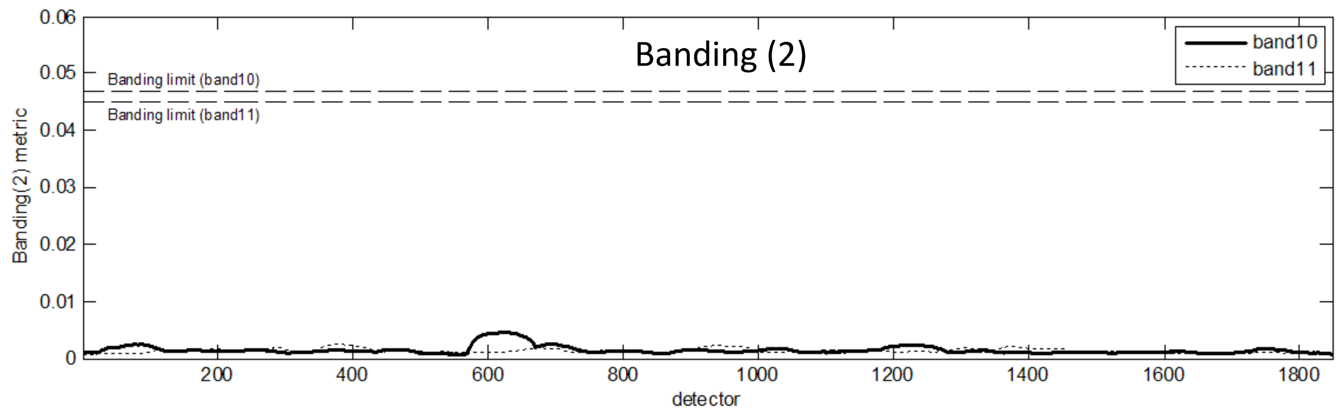
- As one example, constructed ‘uniform’ scene from statistics from an ocean image

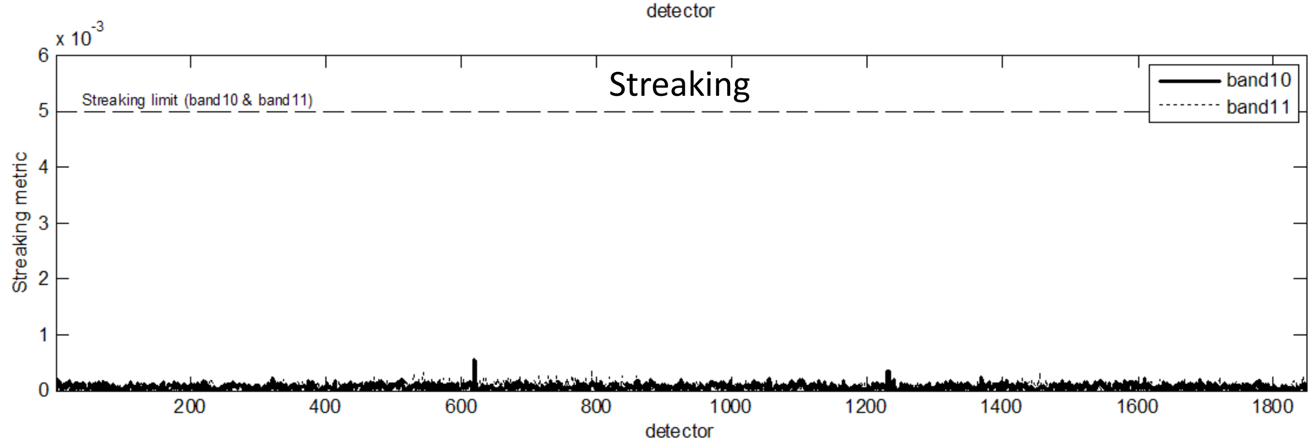


TIRS On-Orbit Performance: Spatial Uniformity (2)

- For this particular scene, TIRS meets the banding/streaking uniformity requirements

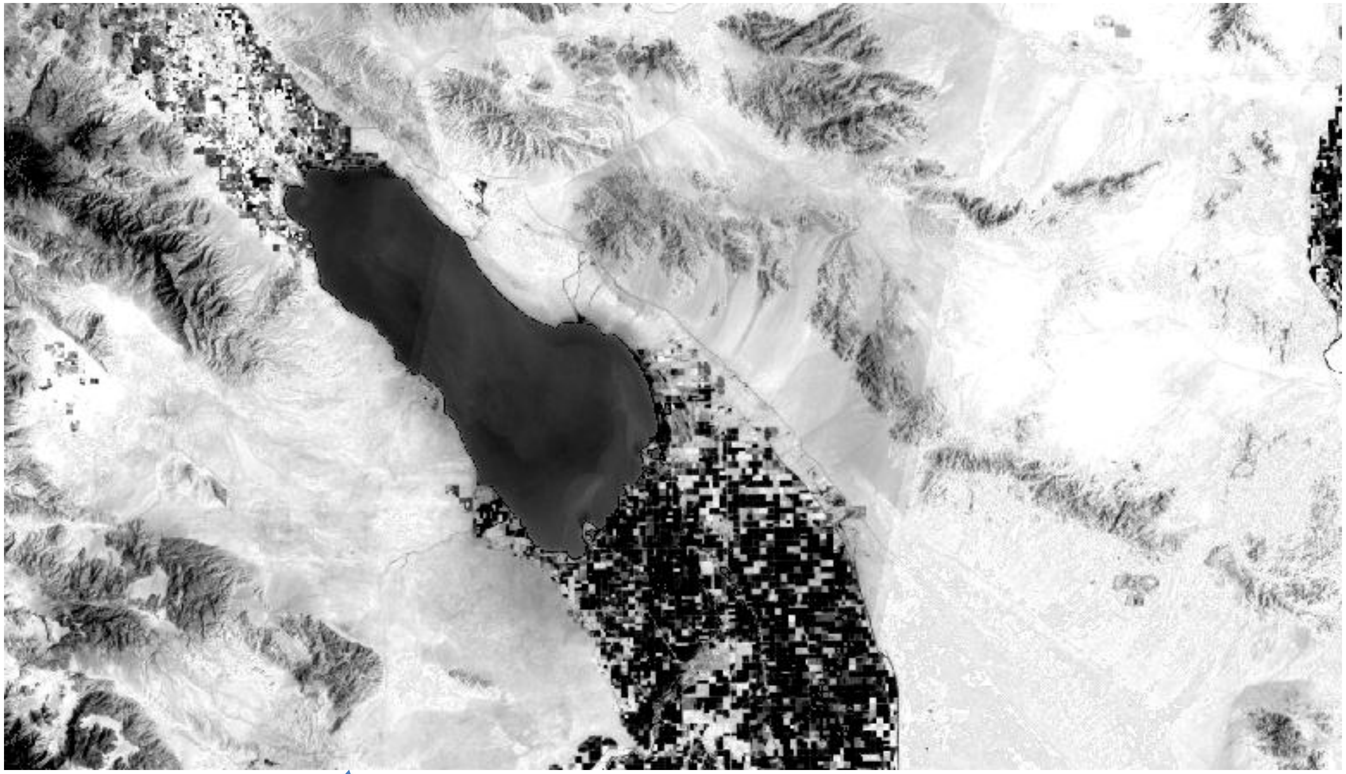






TIRS On-Orbit Performance: Spatial Uniformity (3)

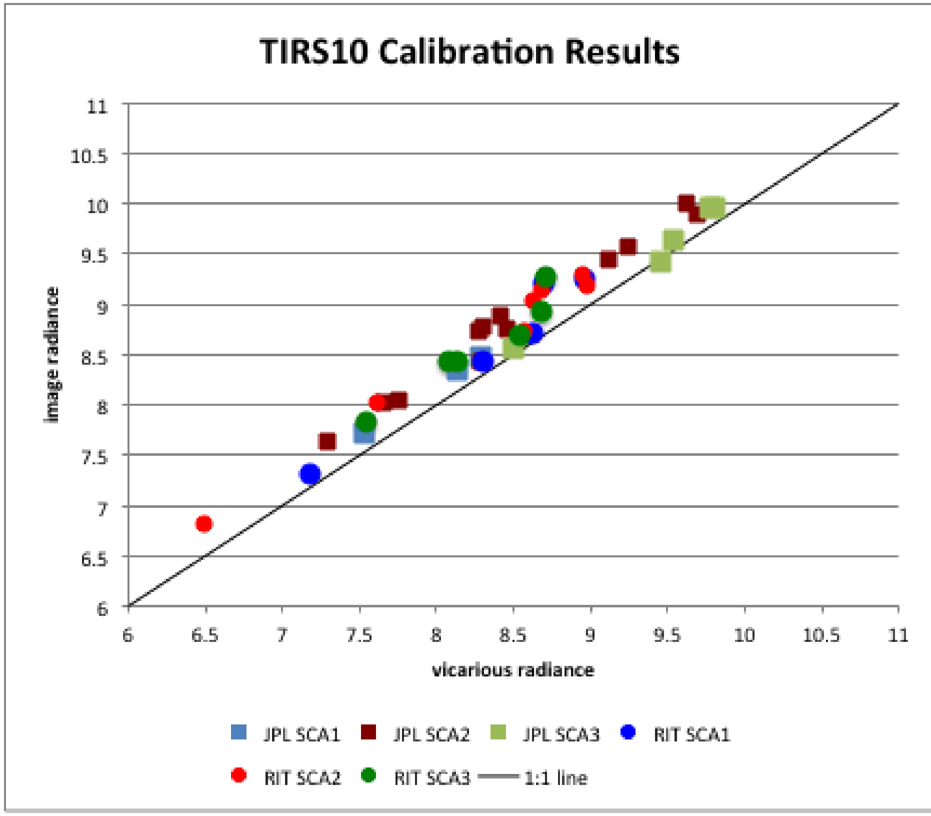
- Other scenes exhibit banding artifacts. Example: Salton Sea in California
- Banding between the three focal plane arrays as high as 3% in band 11

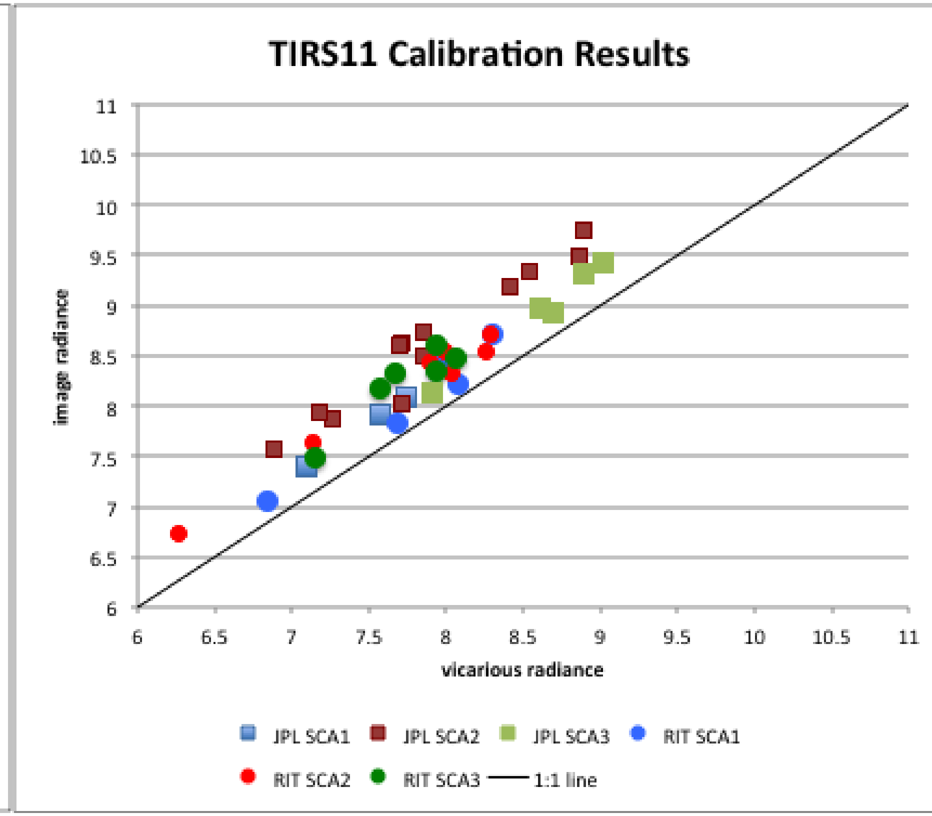


Banding between arrays

- Currently working to understand this behavior

Absolute Calibration: Comparison to Surface Measurements propagated through Atmosphere



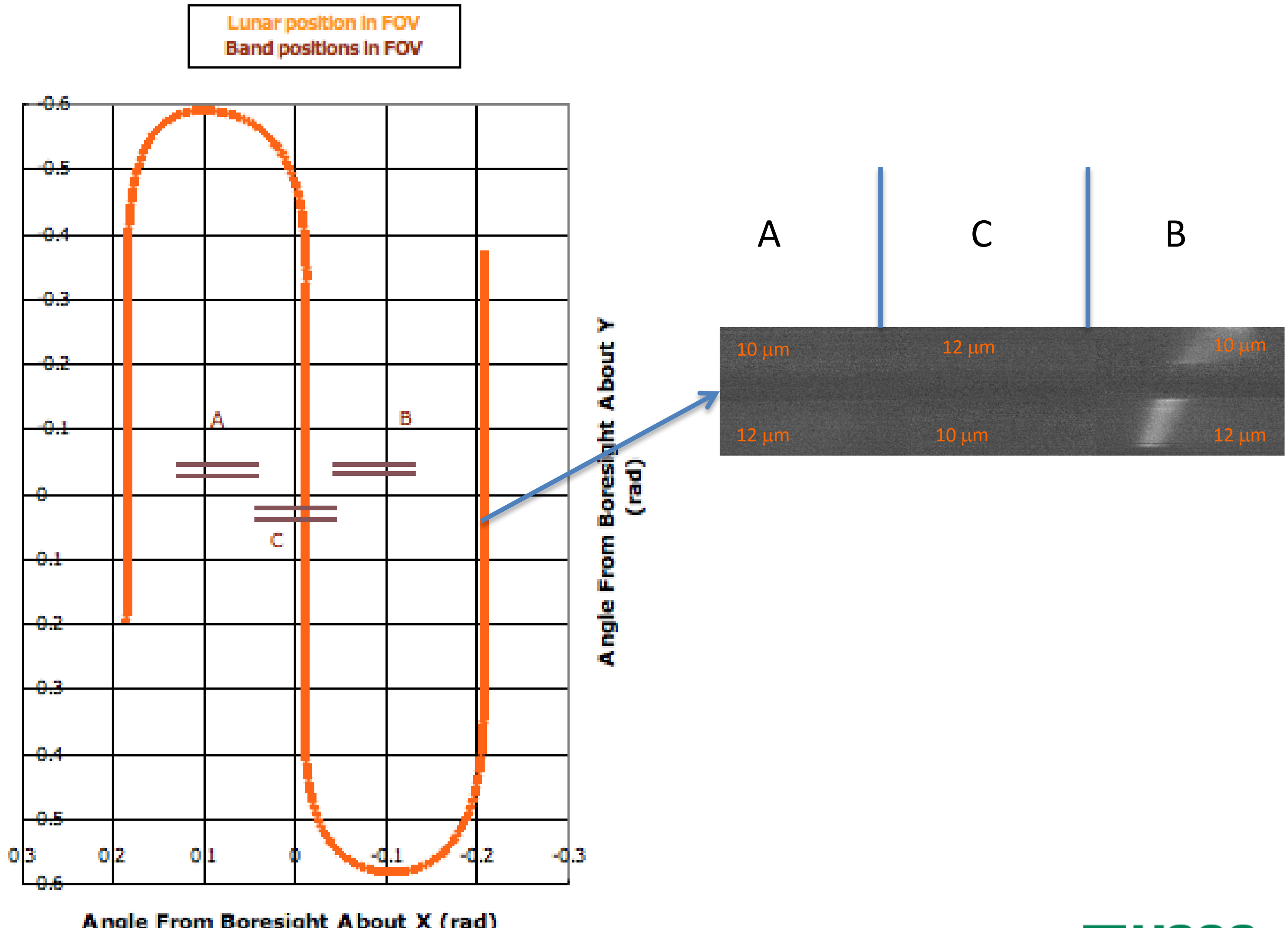


TIRS is reporting higher temperatures than expected (by 2 K +)
Significant variability in results, particularly in band 11 (12 micron band)

Understanding TIRS Non-Uniformity and Absolute Calibration Variability

- TIRS non-uniformity varies with scene content
- Significant variability in differences between TIRS calibration and vicarious results
- Working hypothesis is that this is the same phenomena: TIRS out-of-field (OOF) response or ghosting
  - TIRS out-of-field response modeled and partially characterized prior to launch – no significant ghosts predicted or found within telescope FOV
  - On reexamination of pre-launch, some evidence of further out-of-field ghosts
- Two pronged approach
  - Use moon as a source for on-orbit ghost characterization; assess if magnitude of ghosts is sufficient to explain variability (optical modeling)
    - Data acquired while slewing to the moon have shown weak (<0.4%) ghosts in TIRS data beyond the focal plane assembly extent FOV
      - These slews sample a very small range of the TIRS OOF response
    - Special TIRS lunar ghosting collects scanned a larger range of angles around moon—initial examination consistent with an annular ghosting pattern
  - Continue characterizing variability using vicarious methods

TIRS Extended Lunar Scans (Day 289)



From Allen Lunsford

TIRS Absolute Calibration under study

- Vicarious Calibrations
  - Multiple variables
    - Location in focal plane
    - Temperature
    - Scene content/contrast; day/night
  - Data limitations
    - Fixed cal sites routinely occur at same location in focal plane
      - Point off-nadir for some acquisitions (nighttime) to move location with focal plane
    - Automated access to TIRS data established
    - Increased nighttime acquisitions over coastal US regions
- Implementing Band 10 bias adjustment of -0.32 W/m2 sr μm
  - Reprocessing of already acquired data

Summary

• TIRS is performing well in terms of noise and stability when viewing on-board calibration sources.

- Large margin on NEΔL and NEΔT and stability requirements

• TIRS meets banding/streaking uniformity metrics on certain Earth scenes yet fails these metrics on others.

• On-going analysis on banding/streaking and absolute calibration issues

- Special lunar collects to characterize ghosting

Reexamination of TIRS stray light model

- Enhanced vicarious analyses

CPF Update/Reprocessing Summary

- TIRS
  - Change band 10 absolute calibration by -0.32 W/m^2 sr μm
- OLI
  - Change Cirrus band reflectance calibration by ~7%
  - Increase precision of radiance to reflectance conversion coefficients (<0.3%)
  - Adjust edge detector relative gains
- Timing
  - This week
  - Completion

Image Examples of Enhanced L8 Performance

Landsat-8 Enhancements include:

(1) refined spectral bandpasses to avoid atmospheric absorption features or **to provide better contrast**,
(2) additional spectral bands at 443 nm for coastal and aerosol studies and **1375 nm for cirrus cloud detection**,
(3) splitting the ETM+ thermal band into two spectral bands to allow better surface temperature retrievals,
(4) 12 bit radiometric resolution as opposed to 8-bit,
(5) sufficient **radiometric range** to cover 100% diffuse reflecting targets at the minimum solar zenith angle observed with the 10 AM equatorial crossing orbit
(6) **improved noise performance**.

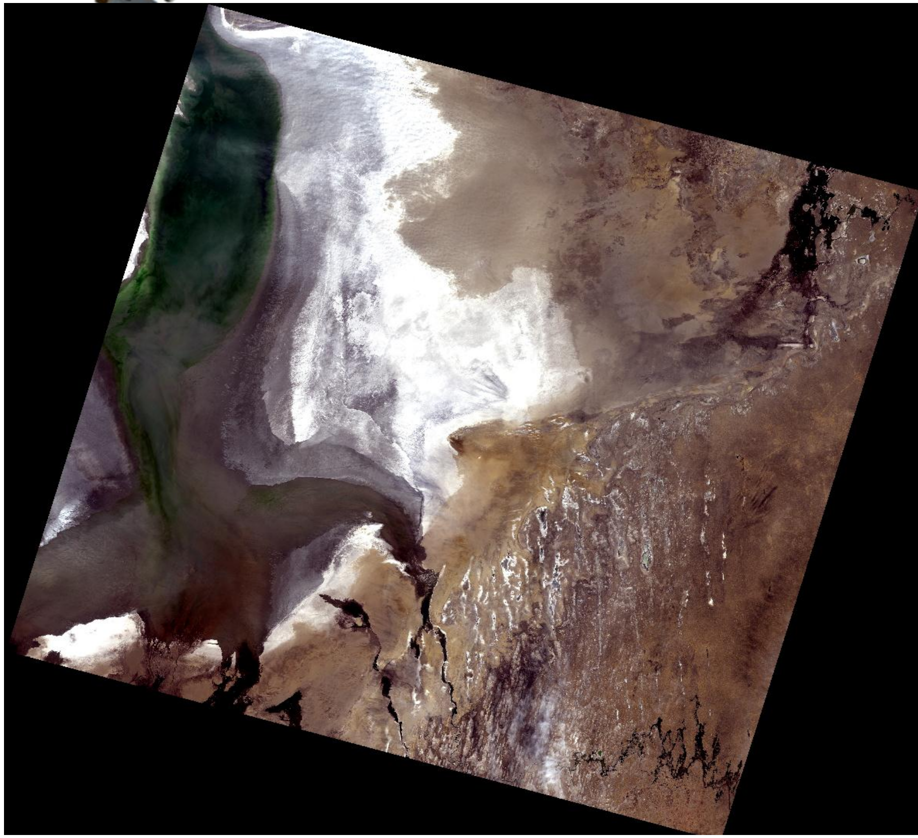
Panchromatic Bandpass Refined

Landsat-7 ETM+

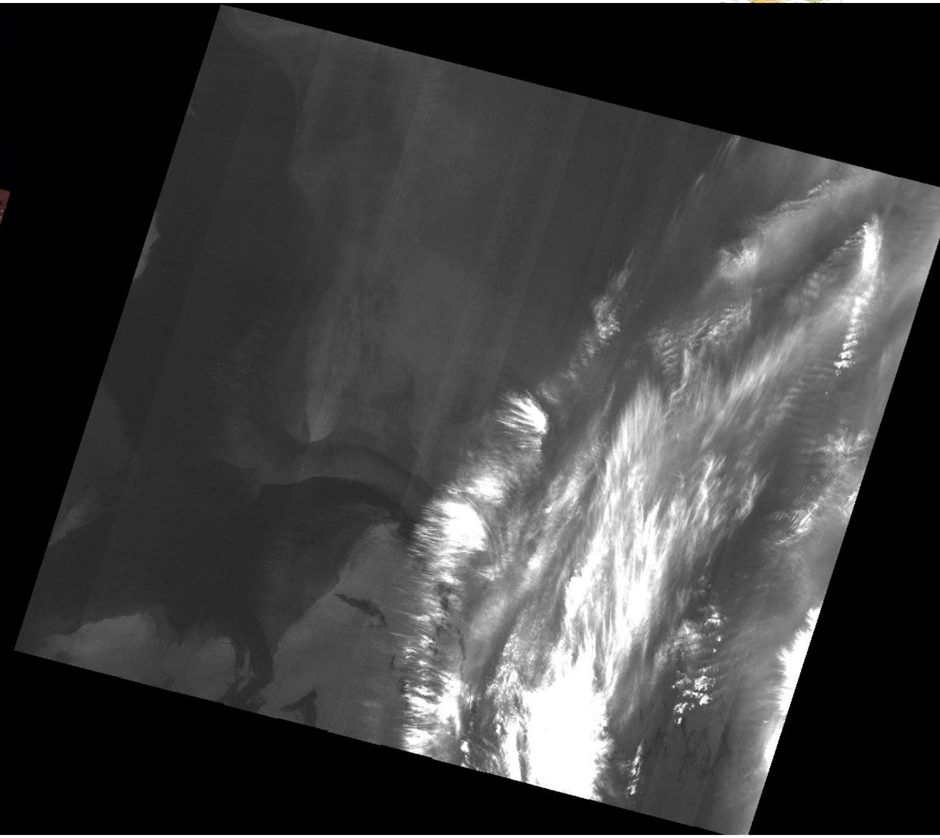
Landsat-8 OLI

Path 38 Row 37 March 29, 2013

New Cirrus Detection Band



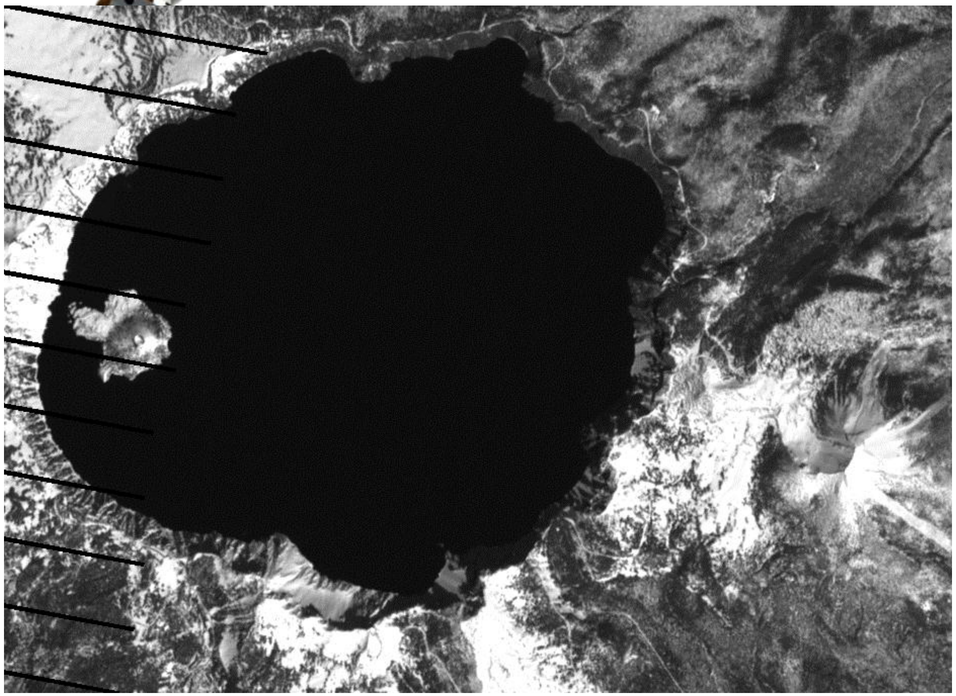
OLI natural color (4,3,2)



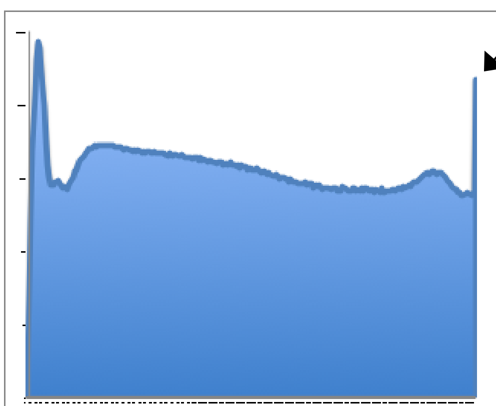
Cirrus band (9)

Images prepared by P. Scaramuzza, EROS

Increased Saturation Radiance



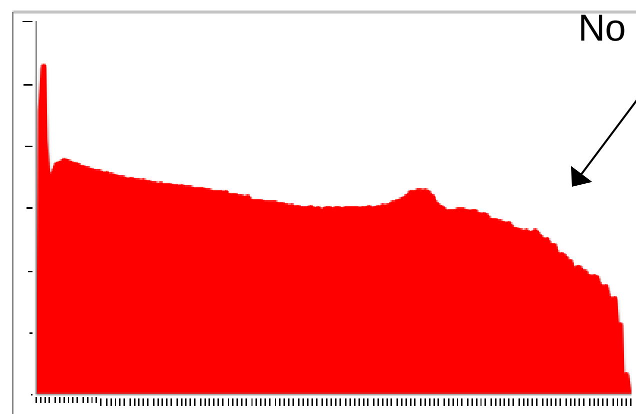
L7 ETM + Pan Band



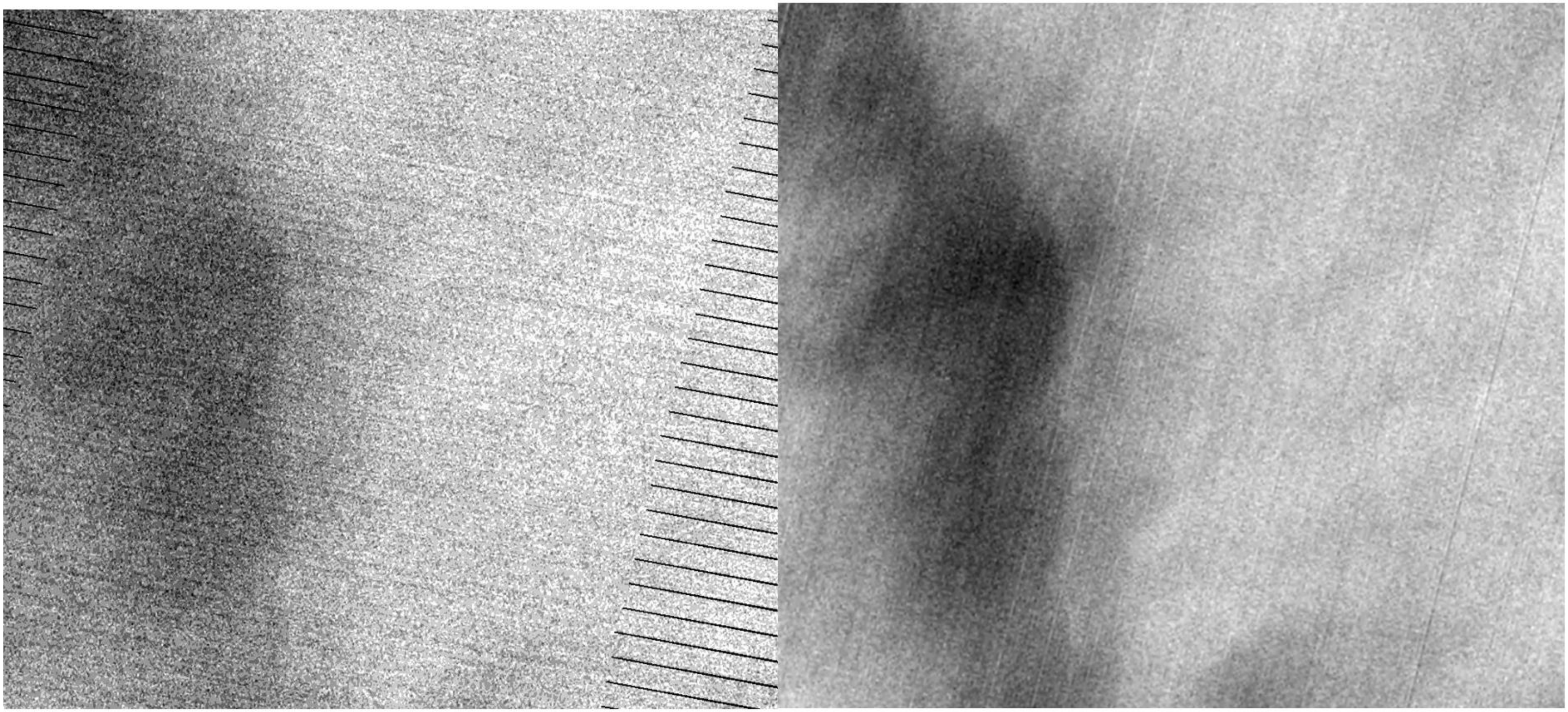
Saturated over snow

L8 OLI Pan Band

No Saturation



Improved Thermal Band Noise



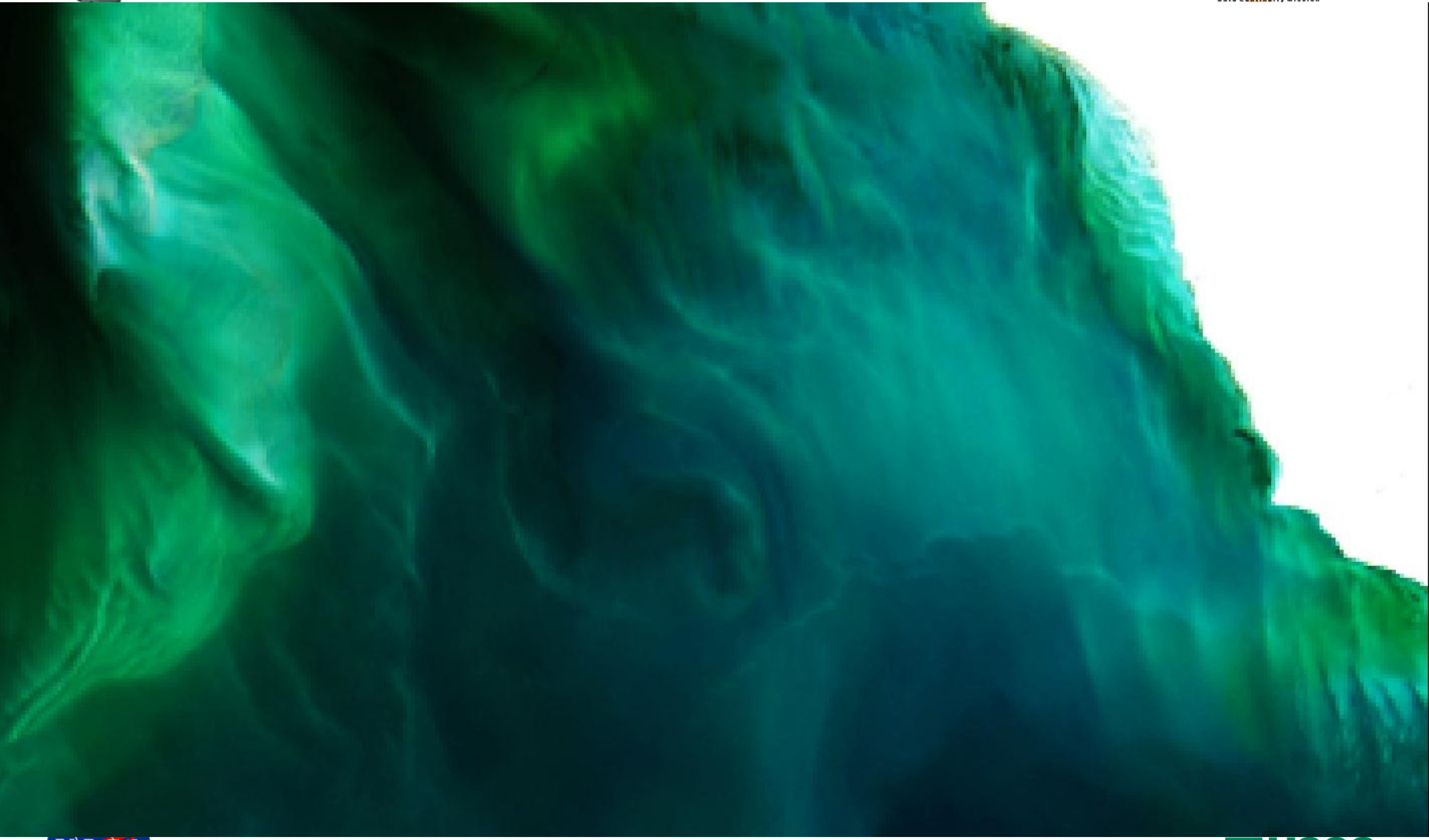
Landsat-7 ETM+ Band 6

Landsat-8 (TIRS) Band 10

Landsat-7 ETM+ Natural Color (3,2,1)

From Pat Scaramuzza, EROS

LDCM OLI Natural Color (4,3,2)



From Pat Scaramuzza, EROS

Landsat-7 ETM+ Natural Color

From Pat Scaramuzza, EROS

From Pat Scaramuzza, EROS

LDCM OLI Natural Color